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Regional Remediation Team

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July 14, 1995

Mr. Eugene Dennis (3HW24)
U.S. EPA, Region III
Central Penn Section
841 Chestnut Street
Philadelphia, PA 19107-4431

RE: Tyson Superfund Site

Dear Mr. Dennis:

Attached for your review are the revised pages for the Focused Feasibility Study (FFS) Draft Report submitted on November 4, 1994, as well as our responses to EPA and PADER comments previously submitted to you on May 1, 1995. Please note that the May 1, 1995 document has not been changed. In order to facilitate your review of the FFS modifications, a redline version of the changes is included. The major revisions are summarized below and reflect the following input:

- Internal review for consistency and consideration of supplemental FFS work (i.e. Sensitivity Analysis of Wet Soil Cover alternative).

- EPA and PADER written comments received on March 29, 1995.

- Issues raised by EPA and PADER at our May 11, 1995 meeting.

In addition to the changes listed below, the Executive Summary was revised as appropriate.

<u>Internal Review</u>

The objective of the FFS was to evaluate which general response action, containment or removal, best met the remedial goals for the site. The development of specific details regarding the design and operation of the alternatives was deferred until the remedial design phase. Chapter 4 was revised so that our recommendation is consistent with this viewpoint.

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Chapter 2, 3 and Appendix H were modified to reflect the supplemental work conducted in support of the Wet Soil Cover alternative (i.e. Sensitivity Analysis; update of conceptual design).

EPA and PADER Written Comments

While the EPA and PADER comments raised several important design questions regarding the Wet Soil Cover alternative, specific details regarding the design and operation of the alternative were deferred until the remedial design phase. Without the benefit of a detailed engineering evaluation, we addressed the comments as completely as possible based on current knowledge in our May 1, 1995 response. As we have agreed, our response to EPA and PADER comments will remain as a supplemental document to the FFS Report rather than attempting to incorporate specific engineering issues into the report text.

EPA and PADER Discussions

From our discussions on May 11, it appears that most of our responses adequately addressed the EPA and PADER comments. Key issues raised by EPA were: 1) clarification of the recontamination mechanism, and 2) whether excavation of those saturated soils periodically exposed due to natural fluctuations in the groundwater table would mitigate vapor migration and subsequent risk.

As we discussed, excavation of DNAPL-impacted soils below the water table would further increase the implementation risk to the extent of negating the incremental benefit in residual risk achieved by the additional removal. Regardless of the degree of excavation, VOC vapors from the underlying DNAPL-affected bedrock would continue to migrate upward through the soils resulting in long-term residual emissions, for as long as DNAPL-impacted groundwater remains in the saturated bedrock. Chapters 1, 2 and 4, as well as Appendix C, D and F, were updated to emphasize these facts.

For your information, supplemental data gathered from the groundwater level monitoring conducted during the SVE shutdown will be submitted to you in July. We believe this data will be essential to the final design and monitoring of the engineered cover system.

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If you need further clarification or additional information, please call me at (908) 914 -2812.

Sincerely,

R. Keith Harold

R. Keith Harold
Technical Manager

cc: M. Timcik, PADER

Regional Remediation Team

ciba

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November 8, 1994

Mr. Eugene Dennis (3HW24)
U.S. EPA, Region III
Central Penn Section
841 Chestnut Street
Philadelphia, PA 19107

RE: Tyson Superfund Site

Dear Mr. Dennis:

Enclosed for your review and comment is the draft Focused Feasibility Study (FFS) Report. This FFS recommends a final remedial action for the lagoon area soils in accordance with the Consent Decree executed on June 20, 1988.

This report is the cumulation of an exhaustive evaluation of potential remedial technologies and subsequent alternatives. A number of key site-specific factors were identified as critical components of this evaluation process. For example, the current SVE system, although approaching an asymptotic limit of VOC mass removal, has preferentially removed approximately 50% of the more volatile and mobile VOC constituents, leaving the upper few feet relatively clean. In addition, the relatively small mass of residual VOC contaminants left in the lagoon area soils has no significant potential to further degrade groundwater quality because of the extensive DNAPL present in the underlying bedrock aquifer. Also, emissions from VOC contaminants present within the lagoon area soils and particularly from the underlying DNAPL-affected bedrock will pose potential exposure risks following implementation of any remedial alternative, regardless of the degree of treatment.

We believe our recommendation provides the best balance between achievement of the remedial action objectives, consideration of the unique site characteristics and future actions associated with groundwater remediation. After your review, we would like to have a meeting to discuss our recommendation and supporting rationale.

Regional Remediation Team

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If you need further clarification or additional information, please call me at (908) 914-2812.

Sincerely,

R. Keith Harold

R. Keith Harold, P.E.

cc: M. Timcik, PADER

AR315942

FINAL DRAFT REPORT

Focused Feasibility Study: Lagoon Area Soils

Tyson's Site
Montgomery County, PA

Submitted by:

Tyson's Site RPs

4 November 1994

Ciba-Geigy Corporation
Environmental Resources Management, Inc.
ENVIRON
Applied Groundwater Research, Ltd.

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INTRODUCTION

The purpose of this Focused Feasibility Study (FFS) is to identify and evaluate potential remedial alternatives and to recommend a final remedial action to address contaminated lagoon area soils at the Tyson's Site. This FFS has been conducted in accordance with the Consent Decree (CD) executed on 20 June 1988 by the United States Environmental Protection Agency Region III (EPA) and as specified in the FFS Work Plan, dated 30 June 1994, and approved by EPA in a letter dated 13 October 1994.

BACKGROUND

The Tyson's Site, located in Upper Merion Township, Montgomery County, Pennsylvania, is a 4-acre abandoned septic and chemical waste disposal site, adjacent to the Schuylkill River. Past activities in the former lagoons have resulted in contamination of soils and ground water with a number of volatile organic compounds (VOCs), including 1,2,3-trichloropropane (TCP), xylene, toluene and ethylbenzene. Estimates of VOC mass at the site indicate that the vast majority of contaminants are present within the dense non-aqueous phase liquids (DNAPLs) occupying the fractured bedrock aquifer, and that less than 5% of the mass remains as residual VOC contamination distributed throughout the lagoon area soils.

REMEDIAL ACTIVITIES

The EPA issued a revised Record of Decision (ROD) in March 1988 specifying soil vapor extraction (SVE) as the selected remedy for lagoon area soils. The ROD also specified the installation of a ground water recovery and treatment system to prevent the discharge of site-related compounds in ground water from entering the river. The Responsible Parties (RPs) signed a CD on 20 June 1988 to implement the ROD.

A full-scale SVE system, installed at the Tyson's Site in November 1988, has successfully removed approximately half (nearly 200,000 pounds) of the VOC mass initially present in the lagoon area soils. In addition, SVE has preferentially removed the more volatile and more mobile constituents, which has resulted in the upper few feet of soil being relatively clean. However, SVE performance has been limited by low contaminant volatility, soil heterogeneity, soil moisture and low soil temperature which have contributed to declining VOC removal rates. Despite numerous enhancements and modifications employed to improve performance, the SVE system has reached a low asymptotic limit of mass removal and will not achieve the cleanup standards for SVE specified in the March 1988 ROD. Thus, in accordance with the CD, this FFS has been conducted to recommend a final remedial action for the lagoon area soils.

The ground water remediation program commenced in December 1988 with the installation of a ground water recovery and treatment system at the site. As part of a subsequent ROD (1990), additional recovery wells were installed to ensure plume containment. An additional ground water Remedial Investigation (RI) is underway to address several site-related issues regarding the bedrock aquifer.

REMEDIAL ACTION OBJECTIVES

The primary remedial action objective for the Tyson's Site lagoon area soils is the protection of human health through the reduction of potential exposures to hazardous constituents, so as to achieve acceptable risk levels (i.e., within or less than EPA's guideline target cancer risk range of 1×10^{-6} to 1×10^{-4}, and below EPA's non-carcinogenic hazard index of 1.0) in a practical, technically proven, timely and cost-effective manner. Among the routes of exposure evaluated (dermal contact, inhalation and ingestion), inhalation of VOC emissions is the most significant pathway contributing to the estimated carcinogenic risks.

KEY FACTORS CONSIDERED IN THE FFS

The following site-specific factors significantly affect the development of the remedial alternatives and provide the basis for detailed alternatives evaluation, comparison and recommendation:

- Because of the extensive DNAPL present in the bedrock aquifer and the resulting high contamination levels of soluble VOCs present in ground water, the relatively small mass of residual VOC contaminants in the lagoon area soils has no significant potential to further degrade ground water quality. Consequently, protection of ground water from contamination present in the lagoon area soils is not considered in the development of the remedial action objectives. The appropriate remedial action for the lagoon area soils must be consistent with the objectives and timeframe for the ground water remediation, considering that remediation of the DNAPL in bedrock will not be achieved within the foreseeable future.

- The physical nature of the site and the requirement for long-term operation and maintenance of the ground water remediation program will limit potential future use of the property, regardless of the final remediation performed for the lagoon area soils. Control of the former lagoon area and adjoining property is being obtained from the current owners. Institutional controls are anticipated to prevent general public access.

- Increased levels of volatilization and short-term VOC emissions will be generated during the implementation of any remedial alternative that includes soil removal activities. The ability to control short-term fugitive VOC emissions generated during various components of the excavation process was evaluated and appropriate control measures were defined.

- The volatilization of organic compounds present within the lagoon area soils and particularly from underlying DNAPL-affected bedrock generates VOC emissions to the atmosphere, posing potential exposure risks following implementation of any remedial alternative. Regardless of the degree of excavation, VOC vapors from the underlying DNAPL-affected bedrock would continue to migrate upward through the lagoon area soils resulting in long-term residual emissions from the ground surface, for as long as DNAPL-impacted ground water persists in the saturated bedrock.

- Because of the site-specific DNAPL conditions, soil recontamination has been evaluated to determine the anticipated effect on treated or clean soils. Recontamination of treated or clean borrow soils will result from the upward migration of VOC vapors caused by DNAPL-impacted ground water in the saturated bedrock. Additionally, recontamination of treated or clean soils placed near the saturated zone will occur due to natural fluctuations in the ground water table. This will result in long-term residual VOC emissions and subsequent risk.

- The soil removal and treatment alternatives consider removal of only unsaturated soil with average total VOC concentrations greater than 1,000 mg/kg, which represents approximately 99% of the VOC mass in the unsaturated soils. Excavation of DNAPL-impacted soils below the water table, even if it were feasible, would further increase the implementation risk to the extent of negating the incremental benefit in residual risk achieved by additional removal.

- Contaminated saturated zone soils are considered as part of the ground water regime currently addressed by the ground water remediation program, and as such, are not included in this FFS. Based on a detailed evaluation, the marginal benefits from protecting the clean or treated backfilled soils using subsurface barrier technologies are offset by implementation and effectiveness concerns.

- The reduction of surface water infiltration and protection of ground water is not an established requirement for any of the remedial alternatives. No further significant degradation of ground water quality is expected to result from the relatively small VOC mass present in the lagoon area soils as compared to the significant volume present in the saturated bedrock. Additionally, the ground water recovery and treatment system is currently operating to contain migration of affected ground water from the site.

ALTERNATIVES DEVELOPMENT

A large number of potentially applicable technologies, representing a broad range of remedial action categories, has been identified. These technologies have been evaluated and screened in terms of effectiveness, implementability, cost, and the ability to satisfy the remedial action objectives for the lagoon area soils. Additionally, several promising remedial technologies were tested in bench and pilot-scale studies. The technologies that best satisfied the initial evaluation criteria were assembled into a focused list of potential remedial alternatives. These alternatives were grouped into the following two general response action categories:

1. Containment (Soil Cover, Capping, Wet Soil Cover); and:
2. Excavation (Low Temperature Thermal Desorption (LTTD) and Off-Site Incineration/Disposal).

A description of the remedial alternatives is provided in Table ES-1.

ALTERNATIVES EVALUATION AND COMPARISON

A detailed evaluation of each alternative according to the nine evaluation criteria of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) was completed, including a comprehensive and quantitative risk assessment. This evaluation is followed by a comparative analysis to identify the relative advantages and disadvantages of alternatives and to provide a basis for the recommendation and selection of the most appropriate remedial alternative for the lagoon area soils.

The Containment general response action, or specifically the Capping and the Wet Soil Cover alternatives, provide the greatest overall protection of human health. The total estimated carcinogenic risks for the exposure populations associated with these alternatives are generally not significant (i.e., $<1x10^{-6}$). The Soil Cover alternative is less effective at controlling VOC emissions than the other containment alternatives but minimizes total risks to within the target

Table ES-1 Description of Remedial Alternatives

	ALTERNATIVE	DESCRIPTION	OVERALL EFFECTIVENESS
Containment	**Alternative 1 Soil Cover**	Surface soil barrier comprised of a 6-inch vegetated topsoil layer above a 12-inch to 18-inch general fill layer, covering approximately 2.5 acres.	Eliminates potential direct contact and ingestion exposures and provides limited reduction of VOC emissions.
Containment	**Alternative 2 Capping**	Multi-layer cap comprised of a 6-inch vegetated topsoil layer, a 12-inch to 18-inch general fill layer and a 24-inch clay layer covering approximately 2.5 acres. Includes provision for active gas venting beneath the clay layer, if required.	Provides significant reduction of VOC emissions and eliminates potential direct contact and ingestion exposures.
Containment	**Alternative 3 Wet Soil Cover**	Surface soil barrier, with a saturated soil layer, comprised of a 6-inch vegetated topsoil layer, a 6-inch compacted clean soil layer, a 12-inch sand infiltration blanket, an irrigation system, and an 18-inch wet soil layer formed by homogenizing and compacting borrow soils, covering approximately 2.5 acres.	Eliminates VOC emissions and potential direct contact and ingestion exposures. Provides slow reduction in toxicity, mobility and volume by enhancing natural attenuation.
Excavation	**Alternative 4 LTTD**	Excavation of a portion of the lagoon area soils (13,000 cu. yd. of unsaturated soils with average total VOC levels greater than 1,000 mg/kg), on-site treatment by LTTD, and backfilling of the excavated area with treated soil. A soil cover, as described for Alternative 1 will be installed over the entire lagoon area.	Eliminates potential direct contact and ingestion exposures. Reduces long-term VOC emissions but has higher short-term VOC emissions.
Excavation	**Alternative 5 Off-Site Incineration/Disposal**	Excavation of a portion of the lagoon area soils (13,000 cu. yd. of unsaturated soils with average total VOC levels greater than 1,000 mg/kg), transportation of excavated soil by rail to an off-site incinerator/disposal facility, and backfilling of the excavated area with clean imported fill. A soil cover, as described for in Alternative 1 will be installed over the entire lagoon area.	Eliminates potential direct contact and ingestion exposures. Reduces long-term VOC emissions but has higher short-term VOC emissions.

risk range (10^{-4} to 10^{-6}). A summary of overall estimated carcinogenic risk for each alternative is shown in Table ES-2.

The Capping alternative will provide effective VOC emissions control and a high degree of long-term effectiveness with minimal maintenance. The Wet Soil Cover alternative also provides for effective VOC emission control, high long-term effectiveness, and additionally allows for long-term reduction of contaminants by enhancing natural attenuation. Additionally, the Wet Soil Cover may be more compatible with future potential in-situ remediation, if such a technology becomes available.

The Capping and Wet Soil Cover alternatives provide high levels of short-term effectiveness and implementability because these alternatives can be completed in a relatively short time, the short-term risks are minimal, and the benefits will be realized immediately. The Soil Cover alternative is readily implementable but will not provide as high a level of overall effectiveness. The Soil Cover, Capping and Wet Soil Cover alternatives are the most cost-effective remedies evaluated for the Tyson's Site lagoon area soils.

The Excavation general response action, or LTTD and Off-Site Incineration/ Disposal alternatives, will permanently destroy remaining VOC mass in the unsaturated lagoon area soils, thus providing immediate reduction of toxicity and volume through treatment. However, the high implementation risk will more than offset the incremental decrease in residual risk gained by excavation of the soils. Thus the net result of excavation of either the unsaturated or saturated contaminated soils (as long as DNAPL is present in the bedrock) is an increase in total risk as compared to the containment alternatives. Additionally, VOC vapor migration would only be controlled for a short period of time until the clean fill used to replace the DNAPL-impacted soils is recontaminated by DNAPL-impacted ground water in the saturated bedrock. This would result in long-term residual VOC emissions and subsequent risk.

In addition, the LTTD and the Off-Site Incineration/Disposal alternatives are much less effective in the short-term due to increased VOC emissions during the excavation and handling of contaminated lagoon area soils. Both soil removal alternatives are also more difficult and time-consuming to implement. The costs for the LTTD and the Off-Site Incineration/Disposal alternatives are about an order-of-magnitude higher than the containment alternatives because of the significant efforts and expenditures required for the excavation and the treatment/disposal of lagoon area soils.

This FFS concludes that a Containment remedial action, or particularly the Wet Soil Cover alternative, will provide a cost-effective approach to reduce potential overall exposure risks to within or less than EPA's target risk range. Any excavation of lagoon area soils will generate VOC emissions, resulting in increased short-term risks at significantly greater remediation costs. The long-term effectiveness and the risk reduction benefits of any removal alternative will be offset by the increased implementation risks, and will not prevent continued VOC vapor migration and soil recontamination caused by the DNAPL-affected ground water in the saturated bedrock.

RECOMMENDATION

Complete shutdown and removal of the existing SVE system is recommended because continued operation will not result in significant additional VOC mass removal. Continued operation of SVE is not compatible with any of the remedial alternatives.

It was determined through the FFS process that a containment general response action, or specifically the Wet Soil Cover and Cap alternatives, best meet the remedial goals for the site. The Wet Soil Cover is the preferred alternative based on risk reduction, enhanced natural attenuation, prevention of soil recontamination and compatibility with the long-term ground water program. However, final selection of either the Wet Soil Cover or Capping remedy can not be made until the remedial design phase. During that phase, the predicted performance of the wet soil cover would be compared to that of the more conventional clay cap. Such an evaluation would establish the final engineered cover system which best satisfies the following criteria:

- Effective long-term VOC emission control such that implementation risks are minimized and overall risks are reduced to acceptable levels;

- Minimization of contamination of additional soils;

- Compatibility with future remedial actions (i.e. would allow in-situ treatment of soils and bedrock if a technology becomes available); and:

- Cost-effectiveness.

1.0 INTRODUCTION

1.1 PURPOSE

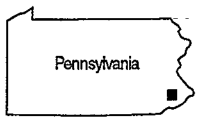
The purpose of this Focused Feasibility Study (FFS) is to identify and evaluate alternatives for remediation of contaminated soils within the area of the former lagoons at the Tyson's Site. Specifically, this FFS will recommend a final remedial action in accordance with the Consent Decree (CD) executed on 20 June 1988 with the U.S. Environmental Protection Agency (EPA).

In November 1988, the Responsible Parties (RPs) began operation of a full-scale soil vacuum extraction (SVE) system. Significant effort has been made and major expenditures (>$40 million) have been incurred over the past six years to install, operate, maintain, and improve SVE performance. As of July 1994, approximately 200,000 pounds of VOCs had been removed from the soils within the former lagoon areas. This represents a significant portion (approximately 50%) of the original VOC mass in the lagoon area soils. The SVE system operation has preferentially removed the more volatile and the more mobile constituents and has left the upper few feet of lagoon area soils relatively clean. As a result, the potential for VOC emissions to the atmosphere and any associated risks have been reduced.

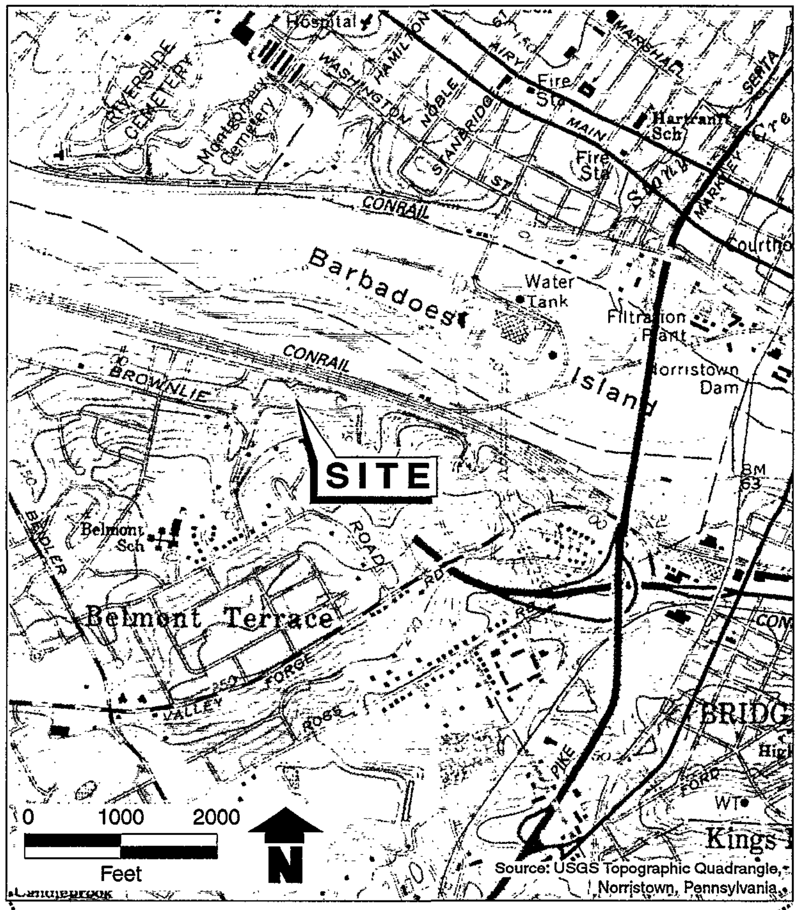
The SVE system VOC mass removal rate has declined with time, and has reached an asymptotic limit of VOC mass removal despite numerous enhancements and modifications to the SVE system. As a result, the SVE system will not achieve the performance standards specified for SVE in the March 1988 Record of Decision (ROD) and the June 1988 CD. Thus, in accordance with Section VIII of the CD, this FFS has been performed by the RPs to evaluate remedial alternatives for these soils.

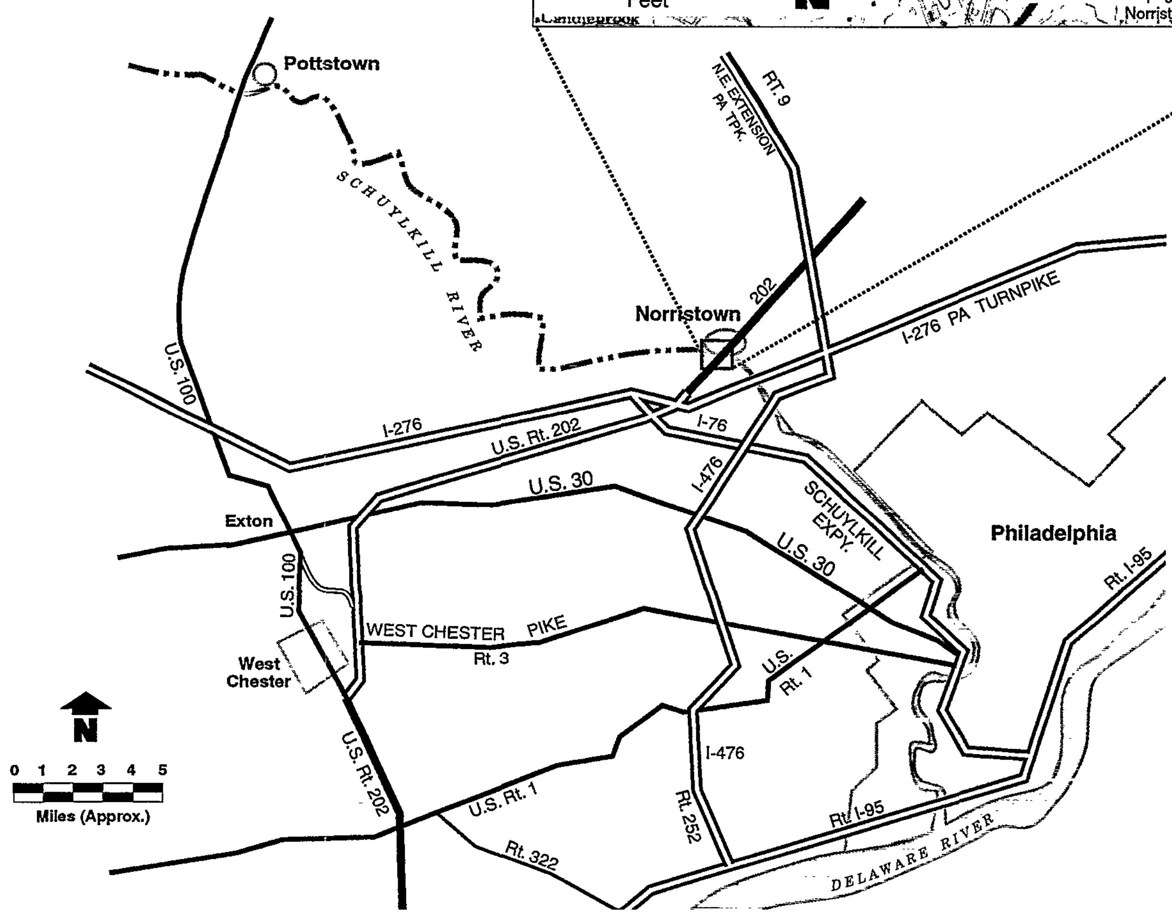
This FFS defines the extent of contaminated soils to be addressed, establishes remedial action objectives and a remediation schedule, and balances the remedial action objectives and alternatives in a manner consistent with the on-going site-wide ground water remediation program. The presence of extensive Dense Non-Aqueous Phase Liquid (DNAPL) source areas in the bedrock aquifer requires the RPs to continue ground water remediation at the site for the foreseeable future. This FFS evaluates potential remedial technologies for the contaminated soils, and develops a number of potential remedial alternatives from the most appropriate technologies. The remedial alternatives are then evaluated

Figure 1-1
Location Map
Focused Feasibility Study
Tyson's Site



Quadrangle Location





and compared based on the CERCLA evaluation criteria. This evaluation serves as the basis for the recommendation of a final remedial action for the Tyson's Site lagoon area soils.

This FFS is organized as follows:

- Section 1: general purpose, background and approach for this FFS, including the key factors to be considered;
- Section 2: development of remedial action objectives and remedial alternatives, including the definition of the areas and volumes to be addressed by the remedial alternatives, identification of applicable and relevant and appropriate requirements (ARARs), screening of potential remedial technologies, assembly of alternatives from the most appropriate technologies, and presentation of the key issues related to alternative development;
- Section 3: description, evaluation and comparison of remedial alternatives; and
- Section 4: summary of the FFS, and recommendation of a remedial alternative with the supporting rationale for its selection.

Various supporting documents are included as appendices at the end of this FFS.

1.2 *SITE DESCRIPTION*

The Tyson's Site is an abandoned septic waste and chemical waste disposal site reported to have operated from 1962 to 1970 within an inactive sandstone quarry. The site is located in Upper Merion Township, Montgomery County, Pennsylvania (Figure 1-1). The approximate 4-acre plot, which consists of a series of former unlined lagoons within a sandstone quarry, is bordered on the east and west by unnamed tributaries to the Schuylkill River, on the south by a steep quarry high-wall, and on the north by a Conrail switching yard. North of the Conrail tracks is the Schuylkill River Floodplain.

Past waste disposal activities at the site, and backfilling of the lagoons in 1973, have resulted in the contamination of the lagoon area soils and associated fill by a number of volatile organic compounds (VOCs). Of these VOCs, 1,2,3-trichloropropane (TCP), xylene, toluene, and ethyl benzene are the primary indicator contaminants. These compounds are distributed throughout the lagoon area soil, and have been detected at levels varying from parts per billion to percent levels (10,000s of parts per million), with non-aqueous-phase liquids identified at many locations.

The disposal of organic compounds in the former lagoons has also resulted in contamination of the bedrock aquifer. Contamination of the bedrock aquifer was caused by downward and lateral migration of DNAPLs from the lagoon area through secondary porosity features (i.e., fractures and bedding planes) in the bedrock. This migration has left a large body of the bedrock aquifer contaminated by residual DNAPL coating the secondary porosity features, and has resulted in dissolution of DNAPL compounds into ground water. An operating ground water recovery system along the bank of the Schuylkill River has eliminated further discharge of contaminated ground water to the south channel of the river. An additional Remedial Investigation (RI) is underway to address outstanding issues regarding the bedrock aquifer.

The unconsolidated materials beneath the Conrail railroad tracks and most of the unconsolidated materials underlying the floodplain have not been affected by site-related compound migration. The 1987 Off-Site RI evaluated these operable units and resulted in a no-action finding by the EPA (September 1988).

As verified in the 28 July 1994 decision letter from EPA Region III, the entire extent of contamination associated with the site (i.e., the areas previously referred to as the On-Site Area and the Off-Site Area) comprises the On-Site Area for the purposes of remedial investigations and appropriate remediation.

1.3 SITE HISTORY AND REGULATORY/REMEDIAL ACTIVITIES

1.3.1 The Initial On-Site Record of Decision

Following a Remedial Investigation/Feasibility Study (RI/FS) performed in 1983 and 1984, EPA Region III issued a ROD for the Tyson's Site on 9 January 1985. The ROD outlined EPA's selected remedial actions for what was then referred to as the On-Site Area (this area is referred to as the "lagoon area" in this FFS). These actions included the following:

- Excavation and off-site disposal of contaminated lagoon soils and wastes to a permitted Resource Conservation and Recovery Act (RCRA) landfill;
- Upgrading of the existing EPA-installed air stripper; and
- Excavation and off-site disposal of contaminated sediments within the tributary which received effluent from the existing air stripper.

Upgrading the air stripper and excavation and disposal of the contaminated sediments were conducted under the initial ROD. The decision to excavate and dispose the lagoon area soils prompted further evaluation as discussed in Section 1.3.2.

1.3.2 *The Second On-Site ROD and its Basis*

Based on the results of the soil vapor extraction (SVE) pilot testing conducted November 1986 and May 1987, the RPs submitted a Comprehensive Feasibility Study (CFS) to the EPA on 15 June 1987. The CFS presented the following major findings:

- Compared with the contaminants situated in the bedrock, the lagoon area soils present an insignificant contribution to ground water contamination at the site;
- Excavation and off-site transportation of the soils would result in unacceptable risks to the public; and
- Contaminants in the bedrock underlying the lagoons would likely recontaminate clean soils replaced into the lagoons.

In March 1988, the EPA issued a revised ROD which presented SVE as the selected remedy. A CD to implement the ROD was signed on 20 June 1988. The major requirements of the ROD included the following:

- Achieve a cleanup level of 50 ppb for four indicator compounds within 26 months of full-scale startup of the SVE operation;
- Install a ground water recovery system along the Schuylkill River to prevent the discharge of site-related compounds in the ground water from entering the river;
- Operate and maintain the existing seep/spring treatment system until such time that it could be replaced; and
- Remediate a limited amount of soil and sediment from the tributary receiving effluent from the EPA air stripper.

All items under this second ROD have been implemented and/or are being conducted.

1.4 *SVE HISTORY AND PERFORMANCE*

In November 1988, the RP's contractor (Terra Vac, Inc.) began operation of the full-scale SVE system with over 96 extraction wells. Terra Vac, Inc. (Terra Vac) continually expanded and modified the extraction system to address limitations of its effectiveness, as discussed in Terra Vac's Vacuum Extraction Operations and Enhancements Report (Terra Vac, 1994). It was determined that several site-specific factors limit the delivery of air to contaminated soil zones. These limiting factors include the following:

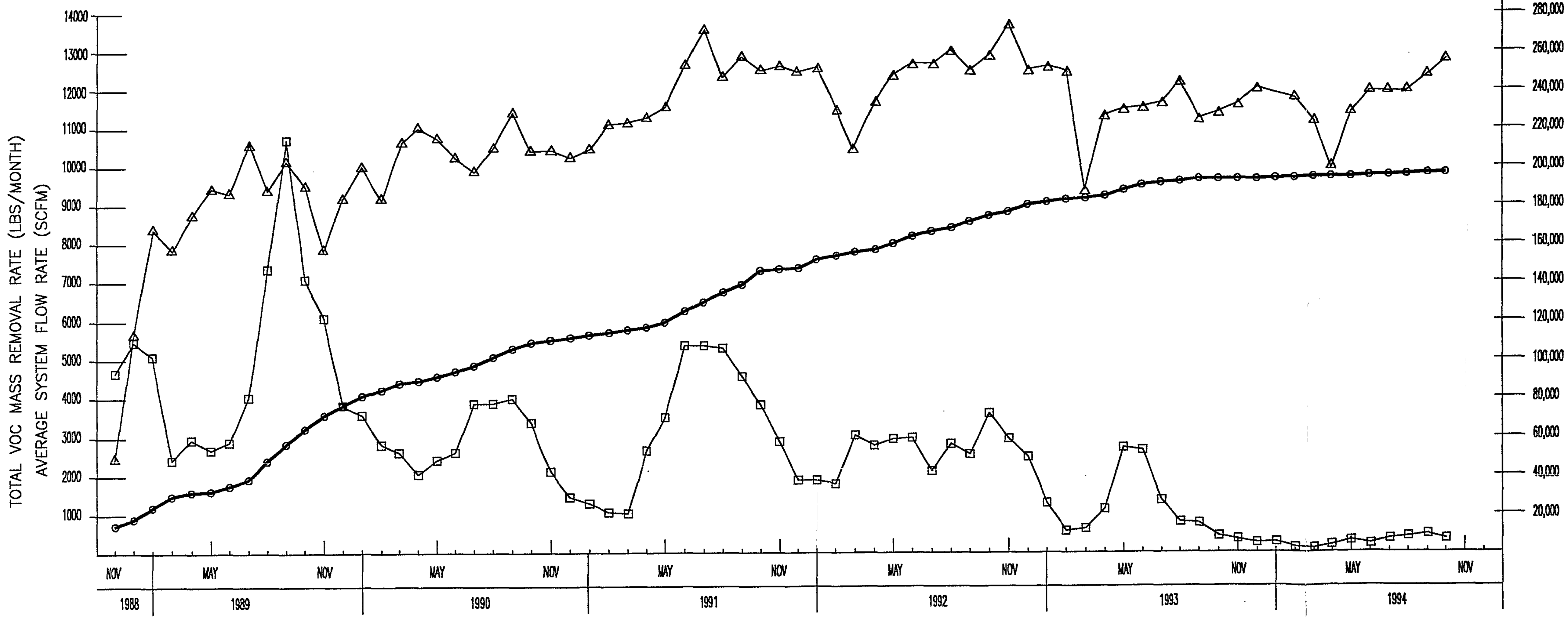
- The site soil is generally very wet. Despite efforts to lower the ground water table with dewatering wells, wet soil conditions persist as a result of high ground water seepage and runoff from the south high wall areas and the northern exposure which limits evaporation.
- The site soil is heterogeneous and includes the presence of clay zones and boulders. Air flow tends to bypass these limited flow zones.
- The site soil contains sludges and DNAPLs that form impermeable zones and limit air flow through the subsoil.
- Tar-like substances, which are formed as the most volatile chemicals are preferentially removed from the DNAPL, result in limited air flow zones.

Without sufficient air flow through the entire contaminant zone, isolated VOCs can be removed only by diffusion into the air flow zone. The diffusion process is slow, depends on the diffusion distance, concentration gradient, and water content. Diffusion through water in the soil matrix (aqueous diffusion) is several orders of magnitude slower than vapor-phase diffusion. Consequently, the SVE system does not work effectively for wet soils in which air flow is restricted and aqueous diffusion limits the mass removal rate.

Figure 1-2 presents the historical summary of SVE performance in terms of air flow rate, monthly mass removal rate and cumulative mass removed. As shown on Figure 1-2, the VOC mass removal rate averaged approximately 5,000 pounds per month during the first year of operation. During the next three years, the VOC mass removal rate averaged less than 3,000 pounds per month. During this period, various measures were attempted to enhance the performance of the SVE system. These enhancement measures included the following:

- Wells were installed to extract VOCs from outside the areas that were influenced by the existing extraction wells (from November 1988 to December 1991);
- The ground surface was covered with a tarp to reduce preferential air flow around wellheads and to reduce rainwater infiltration into the soil (from July 1989 to December 1992);

Figure 1-2
Summary of SVE Performance
Tyson's Site
Focused Feasibility Study



LEGEND:

△ AVERAGE SYSTEM FLOW RATE (SCFM)

□ TOTAL VOC MASS REMOVAL RATE (LBS/MONTH)

o CUMULATIVE MASS OF VOCs REMOVED (LBS)

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- Ineffective extraction wells were removed to induce a more effective flow pattern for extracting VOCs (December 1991 and from January 1992 to June 1993);
- Redesigned wells were installed and screened in the selected intervals of DNAPL and high contamination zones to direct air flow through these zones (from May 1990 to June 1991);
- Horizontal wells were installed to induce an air flow pattern to sweep the subsurface soil more uniformly than vertical wells (from March 1991 to July 1992);
- High vacuum was applied to increase the air flow rate over the low air flow zones (November 1989 to February 1990); and
- Air injecting probes were used to develop new air flow pathways from the injection points to the extraction wells (second quarter 1991).

In addition, Terra Vac performed several field pilot tests to explore further avenues of enhancing the SVE performance as follows:

- Soil temperatures were raised by steam injection (April 1989), hot-air injection (August 1989) and electric heating (May 1991) to increase the volatilization of VOCs;
- Hydrogen peroxide was injected into the soil to assess the feasibility of oxidizing VOC compounds in situ (October 1992);
- Soil mixing using an auger assisted by air injection was employed by Millgard Environmental Corporation to induce a uniform air flow through the soil by homogenizing the soil (first quarter 1992); and
- Soil mixing of small plots was repeated to create new air flow pathways using a backhoe (September/October 1992).

The most effective, and intrusive, of these enhancement measures included expanding the number of extraction wells, replacing ineffective wells with horizontal wells and pilot geomixing of soils. Figure 1-2 depicts the overall trend of declining VOC mass removal rate with time, despite the temporary peaks and valleys caused by enhancement attempts and varying seasonal effects. As illustrated in Figure 1-2, the SVE system has reached a low, asymptotic limit of VOC mass removal effectiveness. Changing the number and type of wells failed to provide sustained increases in VOC removal rates. Geomixing was effective provided it was performed regularly and for prolonged periods.

Recognizing that SVE performance will continue to be limited by contaminant volatility, soil heterogeneity, soil moisture and soil temperature, the RPs discontinued the replacement of wells and geomixing activities in mid-1993 for several reasons. These activities represented continuing operational modifications to the SVE system (geomixing, in particular, is not considered in a typical SVE system design). Both activities resulted in significant intrusive activity, potentially exposing the on-site workers to elevated levels of site-related contaminants. Additionally, evaluation (using controlled bench scale/pilot studies) of potential full scale SVE enhancements is included as part of the FFS.

Despite unfavorable site conditions, the SVE remedy has removed a substantial mass of volatile organics from the lagoon area soils. As of July 1994, a total of 196,155 pounds of VOCs had been removed from the lagoon area soils, which is estimated as approximately 50% of the original VOC mass in the lagoon area soils at the start of SVE. In addition, SVE has preferentially removed the more volatile and more mobile constituents, and has resulted in the upper few feet being relatively clean.

Although a significant portion of the original VOC mass has been removed from the lagoon area soils by SVE, the rate of VOC mass removal has declined with time in response to decreasing contaminant concentrations and mass transfer limitations. As a result, the SVE remedy has not been able to achieve the performance standards established for the SVE system.

1.5 CURRENT SITE CONDITIONS

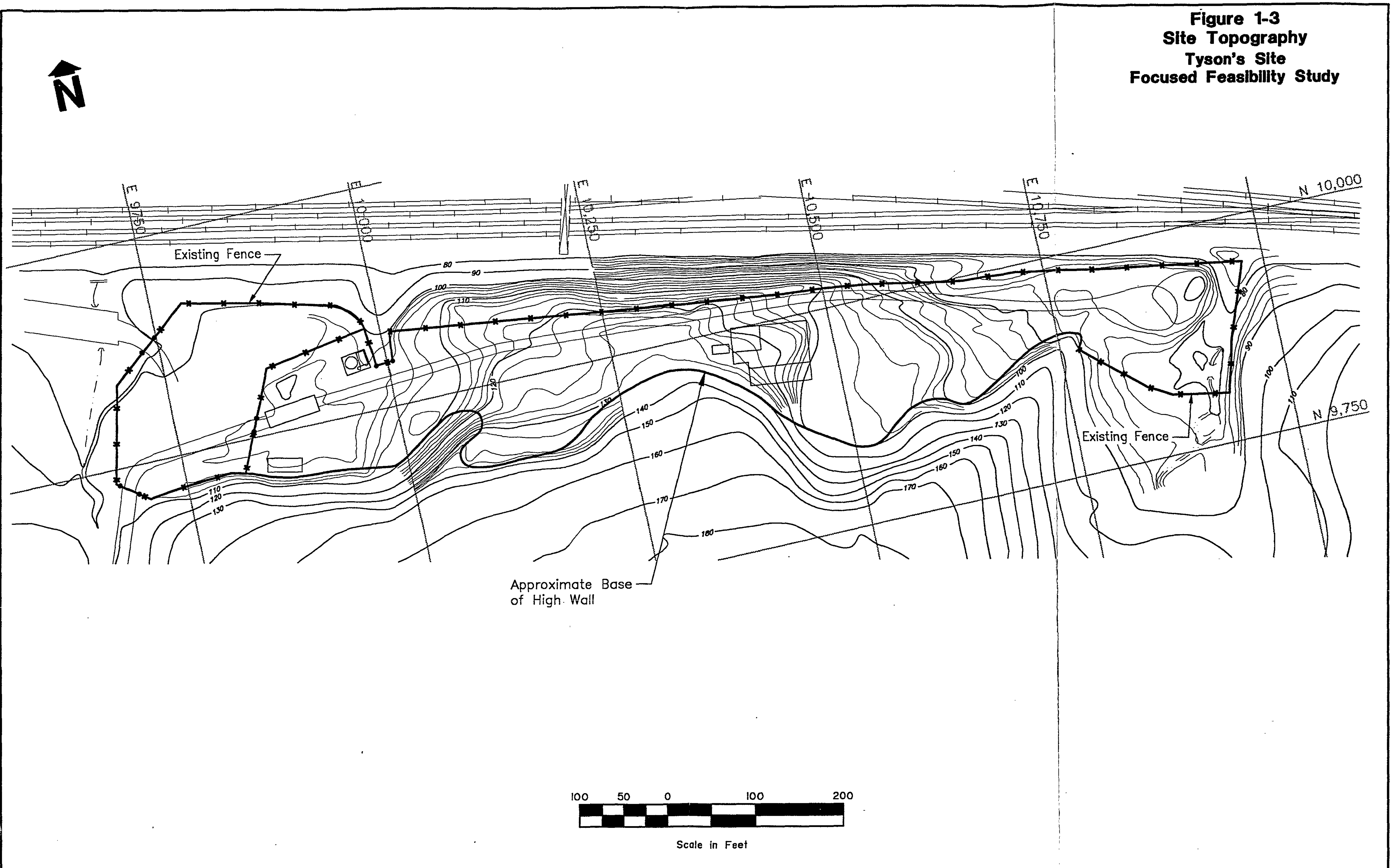
1.5.1 Characterization of Unconsolidated Deposits

1.5.1.1 Physical Characteristics of the Unconsolidated Deposits

The lagoon area soils lie within the upper portions of an arkosic sandstone which was quarried in the early 1900s from the side of a small ridge bordering the Schuylkill River. Separating the lagoon area from the Schuylkill River is a Conrail railroad switching yard and a strip of river floodplain. All of the region north of the railroad tracks lies within the 100-year floodplain except for the ground water recovery treatment buildings. As indicated on Figure 1-3, the site's topography is fairly irregular as a result of quarrying activities, lagoon operation, remedial activities conducted by the EPA and natural processes.

The former disposal lagoons occupy two bowl-shaped depressions in the bedrock surface separated by a distinct bedrock exposure. The unconsolidated materials within the former lagoons consist of disturbed colluvial deposits, quarry rubble and fill material brought in from other

Figure 1-3
Site Topography
Tyson's Site
Focused Feasibility Study



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locations. The thickness of unconsolidated deposits in the upper eastern lagoon is up to 25 feet, while the thickness in the upper western lagoon is up to 15 feet. Top soil is absent or present only as a very thin discontinuous horizon. The grain size of material within the former lagoons is highly variable, ranging from boulder layers that are locally continuous (several feet) to clay. Due to the material variability, correlations of individual layers across a lagoon have not been possible. Generally, soils in the lagoons could be described as silty sands and silty gravels with clay and lesser amounts of cobbles/boulders.

The areas to the east and west of the two disposal lagoons are referred to as the lower east lagoon area and the site support zone, respectively. In these areas unconsolidated deposits generally consist of colluvium (silty sands with some clay). The lower east lagoon has unconsolidated deposits up to approximately 30 feet thick overlying weathered bedrock. The site support zone consisting of unconsolidated deposits of colluvium with some fill has been altered by remediation activities.

1.5.1.2 *Contaminant Distribution in the Unconsolidated Deposits*

A number of organic compounds have been detected in unconsolidated lagoon deposits. The VOCs detected at the highest concentrations include TCP, xylene, toluene and ethyl benzene. These compounds were often detected in percent levels, which is indicative of DNAPLs. DNAPLs have also been visually identified throughout the lagoon area unconsolidated deposits. The DNAPL generally occurs as widespread layers on the bedrock/soil interface, as discrete layers within and below the two nearly continuous layers of gravel and boulders which were identified within the former lagoons, and as discreet "nuggets" of DNAPL in relatively low-concentration unconsolidated deposits.

Results of the Surficial Soil Sampling Investigation (ERM, 1993) indicated that the suite of VOCs and SVOCs in the upper two feet of the lagoon soils is generally consistent with previous investigations, although the concentrations are generally significantly lower than detected during previous subsurface soil investigations.

1.5.2 *Hydrogeology*

Ground water is present in both the unconsolidated lagoon deposits and within the underlying fractured bedrock. Review of water level data collected from wells installed in unconsolidated deposits and bedrock indicate that water is present in unconfined, semi-confined, and perched conditions depending on location. Throughout the unconsolidated deposits of the east and west lagoon areas, ground water is present as a perched zone atop low-permeability layers of silt, clay, and DNAPL sludges. In these areas, bedrock well water elevations can be several feet below water levels measured in wells installed in unconsolidated deposits.

A review of soil data collected during well/boring installation indicates saturated zones at depths of up to 20 feet in the east lagoon and depths of up to 9 to 10 feet in the west lagoon. At the far eastern and far western portion of the site, ground water is found at lower elevations, which generally reflects the ground surface topography. In some locations, bedrock and unconsolidated wells have similar ground water elevations indicating unconfined water table conditions. Figure 1-4 presents a shallow ground water potentiometric surface for the unconsolidated deposits based on ground water level measurements taken February to April 1987, prior to startup of the SVE system.

1.6 KEY FACTORS TO BE CONSIDERED IN THIS FFS

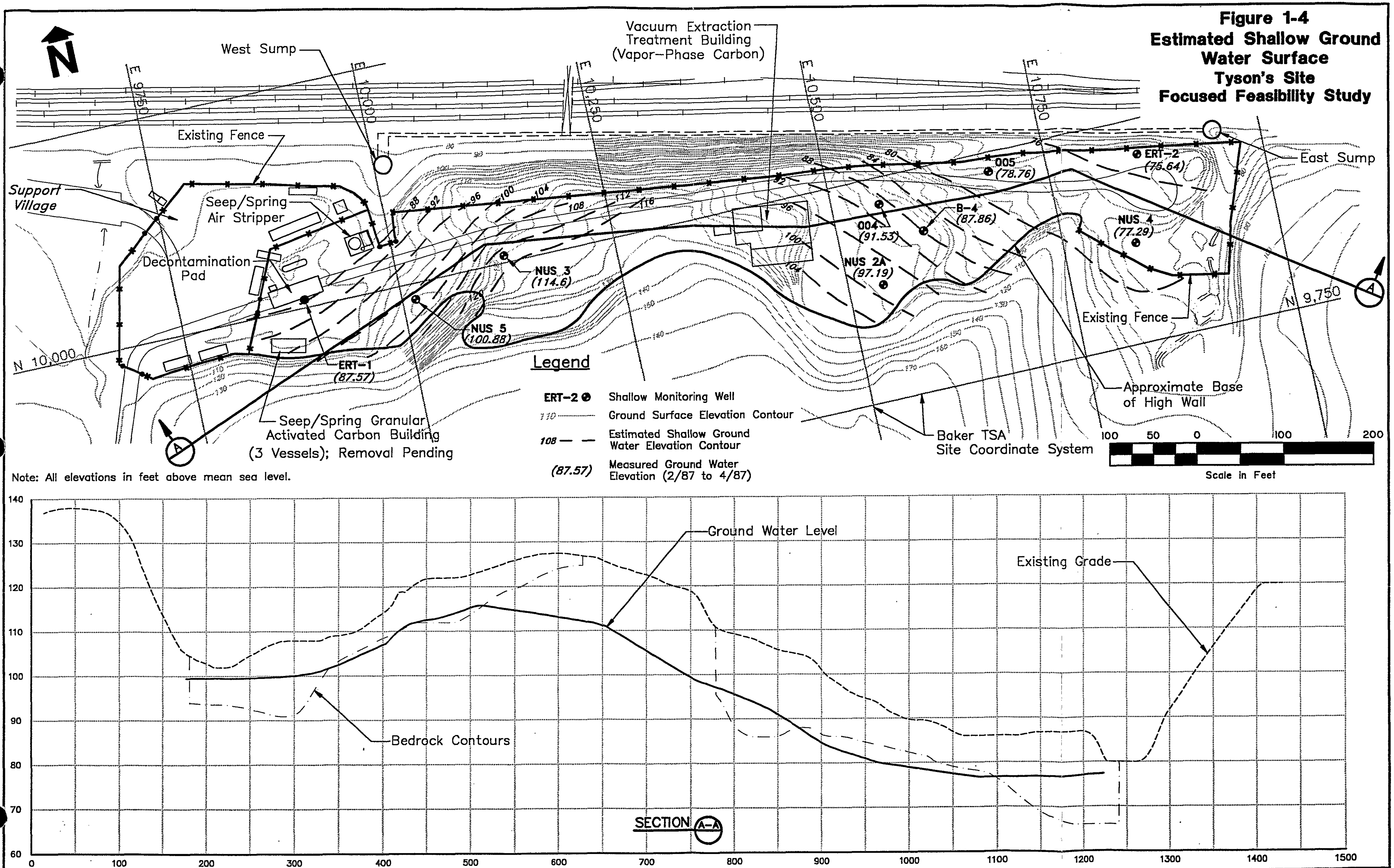
Knowledge of the site conditions and the key factors affecting lagoon area soil remediation has increased significantly since the partial CD was signed in 1988. This is a result of the observations and findings from additional site investigation activities (e.g., Off-Site RI and 1993 Surficial Soil Sampling Investigation) and over five years of SVE system operations. Of particular significance to this FFS are the issues described below.

1) <u>DNAPL Contamination in Bedrock</u>

The nature of bedrock contamination became better known during site remediation activities initiated after the 1988 ROD. Estimates of contaminant mass at the site indicate that the majority of the site's contaminants are found within the DNAPLs occupying the fractured bedrock aquifer (ERM, 1987, 1990, 1992 and 1993). The extensive presence of DNAPLs in the bedrock is a long-term source of continuing bedrock aquifer contamination. Increased understanding of DNAPL behavior and experience at DNAPL-contaminated sites during the past several years have led to the conclusion that the presence of DNAPL in ground water is very difficult and complex to characterize, and that there are no known technologies to effectively remediate extensive DNAPL contamination in fractured bedrock (EPA, 1993e and NRC, 1994).

As a result of this DNAPL, long-term ground water remediation will be required. The overall remedial approach for the lagoon area soils should be consistent with the objectives and schedule for the ground water remediation program, and should consider the fact that remediation of the DNAPL in bedrock will not be achieved within the foreseeable future. If

Figure 1-4
Estimated Shallow Ground Water Surface
Tyson's Site
Focused Feasibility Study



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27222.01.01/08.11.94-TSK/F:\DRAWINGS\TYSON\FO-022.DWG the DNAPL source in bedrock is ever remediated to the point that the lagoon area soils substantially degrade ground water beyond that resulting from DNAPL in bedrock, a revised approach to addressing the lagoon area soils may be appropriate.

2) Ground Water Exposures

Ground water was the primary exposure pathway evaluated in the previous risk assessment pertaining to the 1988 ROD. As long as DNAPL contamination is present in bedrock, the lagoon area soils have no significant potential to further degrade ground water quality. This conclusion is supported by the conceptual soil to ground water partitioning model presented in Attachment A of the Exposure Assessment Memorandum previously submitted to the EPA (14 July 1994). Consequently, exposure to ground water will not be considered in developing remedial action objectives for the lagoon area soils.

3) Future Land Use

Site access by the general public will be restricted. The physical nature of the Site and the need for long-term operation and maintenance of the ground water remediation program will limit future use of the property, regardless of the final remediation performed for the lagoon area soils. Full control of the lagoon property previously owned by General Devices, Inc. (GDI) has been obtained by Ciba from T.A. Raymond, the current owner. Control of other portions of the site which are owned by other parties is in progress. A more detailed assessment of future land use is presented in Attachment B of the Exposure Assessment Memorandum (14 July 1994).

4) VOC Emissions

Recontamination of treated or clean borrow soils will result from the upward migration of VOC vapors caused by DNAPL-impacted ground water in the saturated bedrock. This will cause potential long-term VOC emissions and subsequent risk. Consideration of any containment, excavation and/or treatment remedies should include the potential for VOC emissions and the corresponding risk, and recontamination of the clean backfill or remediated soils. A detailed discussion and evaluation of the potential for vapor-phase recontamination of backfilled soils is presented in Section 2.5 of this FFS.

5) Distribution of Soil Contamination

Knowledge of lagoon area soil conditions gained through operation of the SVE system includes the distribution of contaminant concentrations and total estimated VOC mass. This distribution is used in the evaluation of potential remedial alternatives and in determining the appropriate soil remediation volumes.

1.7 *FFS APPROACH*

This FFS for the lagoon area soils has been conducted in accordance with the applicable provisions of the National Contingency Plan (NCP; 40 CFR 300), and follows the general sequence and intent for conducting Feasibility Studies as presented in EPA's RI/FS Guidance (EPA, 1988).

Based on the development of objectives and criteria to be met by the potential remedial alternatives considered in this FFS (i.e., the remedial action objectives), a broad range of potentially applicable remedial technologies are identified and evaluated in terms of effectiveness, implementability and cost. Those technologies that best satisfy the evaluation criteria are grouped into a focused list of potential remedial alternatives to address the remedial action objectives. Site-specific factors were considered in the development of this focused list.

Following development, each of the potential remedial alternatives is described in detail, with a focus on the key technical and engineering issues related to the effectiveness and implementation of the alternative. A detailed evaluation of each alternative according to the criteria required by CERCLA is then presented. This evaluation includes an assessment of risk for each alternative both during and following implementation. Based on the focused nature of this FFS, an initial screening of alternatives, as suggested in the RI/FS Guidance (EPA, 1988) for feasibility studies, has not been conducted because the initial list of potential alternatives is sufficiently focused. Following the detailed evaluation of alternatives, a comparison of alternatives is presented to identify the relative advantages and disadvantages of the alternatives considered. This FFS concludes with the identification and recommendation of the remedial alternative which best satisfies the overall intent and purpose of the CERCLA evaluation criteria.

2.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES

This section presents the development of remedial alternatives and the supporting rationale, and includes the following:

- Development of remedial action objectives for the lagoon area soils;
- Identification of potentially applicable or relevant and appropriate requirements (ARARs) to be satisfied by the remedial alternatives;
- Characterization of the lagoon area soils to be addressed by the remedial alternatives;
- Identification and screening of various remedial technologies with potential applicability to remediation of the lagoon area soils; and
- Development of a focused list of potential remedial alternatives incorporating the technologies that passed the technology screening process.

2.1 REMEDIAL ACTION OBJECTIVES

Remedial action objectives are identified in this section to provide the basis for the identification and evaluation of potential remedial technologies and alternatives. In consideration of the current site conditions and future actions associated with ground water remediation, the remedial action objectives for the lagoon area soils include the following:

- **Protection of Human Health** by reducing potential exposures to hazardous constituents to acceptable levels (i.e., within or less than EPA's guideline cancer risk range of $1x10^{-6}$ to $1x10^{-4}$, and below EPA's non-carcinogenic hazard index of 1.0). The identified pathways of concern for this FFS include direct contact, inhalation, and ingestion; and
- **Regulatory Compliance** by ensuring that remedial actions comply with all legally enforceable standards.

2.2 IDENTIFICATION OF ARARS

Section 121(d) of CERCLA, as amended by 1986 SARA and the NCP (40 CFR Part 300) require that remedial actions developed for a site meet the following requirements:

- The remedial action must be protective of human health and the environment;
- The remedial action must comply with all Applicable or Relevant and Appropriate Requirements (ARARs), if they exist, unless grounds for invoking a waiver of ARARs are provided. ARARs are used in combination with the remedial action objectives to scope and formulate remedial alternatives for the site.

As defined in "CERCLA Compliance with other Laws" (EPA/540/G-89/006), ARARs are either "Applicable" or "Relevant and Appropriate", but not both. "Applicable" requirements are promulgated cleanup standards, standards of control, or other substantive environmental protection requirements, criteria, or limitations that are generally enforceable under federal or state law and that specifically address a hazardous substance, remedial action, location, or other site-specific condition. "Relevant and appropriate requirements" are federal and state standards, criteria, or limitations that are not legally applicable to the site, yet they address problems sufficiently similar to those found on site that their use is well suited. State standards are applicable or relevant and appropriate only if they are identified by the state in a timely manner and are more stringent than federal requirements.

Other federal and state guidance documents, advisories, or criteria that are not generally enforceable do not have the status of potential ARARs but may be identified as criteria "to be considered" (TBC). TBCs which are not binding may be used to develop remedies when no specific ARARs exist for a chemical or situation, or when such ARARs are not sufficient to be protective.

In this FFS, compliance with established ARARs for the site is considered as one of the remedial action evaluation criteria. If appropriate, the CERCLA provisions for waiving ARARs will be considered, and the grounds for invoking such waivers will be provided. According to the NCP (40 CFR 300.430(f)(1)(ii)(C)), ARARs may be waived by the governing regulatory agency under any one of the following six specific conditions, provided that protection of human health and the environment is still assured:

- The selected remedial action is an interim remedy or portion of a total remedy which will attain the ARAR when complete;
- Compliance with such requirements will result in greater risk to human health and the environment than alternative options;

- Compliance with such requirements is technically impracticable from an engineering perspective;
- The selected remedial action will provide an equivalent standard of performance using another approach;
- The requirement is a state requirement that has been inconsistently applied; or
- The alternative will not provide a balance between public health and environmental welfare and the availability of funds to respond to existing or potential threats at other sites, taking into account the relative immediacy of the threats (for Fund-financed response actions only).

2.2.1 *Types of ARARs*

In accordance with the EPA RI/FS guidance (EPA, 1988), the following three functional groups of potential ARARs and TBCs have been considered in this FFS:

- **Chemical-specific**: requirements that set protective clean-up levels for the chemical of concern, or indicate an acceptable level of risk or rate of release associated with a remedial action;
- **Location-specific**: requirements that restrict remedial actions based on the characteristics of the site or its immediate environment; and
- **Action-specific**: requirements that set controls or restrictions on the design, implementation, and performance levels of activities related to the management of hazardous wastes or contaminants.

Potential ARARs and TBCs for these three groups are identified and discussed for this project in the following subsections.

2.2.2 *Chemical-Specific ARARs/TBCs*

Because this FFS is focused on the remediation of the lagoon area soils only, and site ground water is being addressed as a separate operable unit, ARARs/TBCs will be identified in this FFS only for the lagoon area soils.

2.2.2.1 *Federal ARARs*

There are no chemical-specific Federal ARARs or chemical-specific clean-up standards for the constituents of concern in the soils at the site.

2.2.2.2 *State ARARs*

There are no chemical-specific State ARARs for the constituents of concern in the soil at the site.

<u>*PADER Clean-up Standards for Contaminated Soils, December 1993*</u>: The interim clean-up guidelines for contaminated soils established by PADER in December 1993 are not an ARAR, but may be considered potentially as a TBC. The guidance document provides two sets of clean-up guidelines, one designed to protect the public health and the environment from direct contact exposure, and the other to protect ground water quality. However the document clearly states that the clean-up guidelines published in December 1993 will neither substitute for nor supersede any ARARs that may exist, and should be viewed only as TBC or as a guideline.

The PADER soil clean-up guidelines are based on direct contact non-cancer and cancer risks are considered as TBCs for the soils in this FFS. However, clean-up of site soils with the purpose of protecting ground water quality is neither necessary nor appropriate for this site because the clean-up of lagoon area soil will neither improve the ground water quality nor provide significant protection to the underlying ground water until the DNAPL source in bedrock is remediated to the point that the lagoon area soils substantially degrade ground water beyond that resulting from DNAPL in bedrock. Thus, the clean-up standards based on ground water protection criteria are not considered as TBCs for the constituents found in soil.

For clean-ups involving carcinogens, the PADER document provides the following guidelines for developing a soil remediation strategy:

- Utilize treatment and/or removal technologies that at least achieve a $1x10^{-4}$ excess cancer risk level, supplemented by engineering and institutional controls which increase the overall level of protectiveness to $1x10^{-6}$; or
- Utilize treatment and/or removal technologies that directly meet the cancer risk level of $1x10^{-6}$.

Because risk-based criteria for carcinogens is already provided by applicable CERCLA regulations (40 CFR 300.430 (e) (2) (i) (A)), the Pennsylvania risk-based criteria are not considered as a TBC in this FFS.

2.2.2.3 *Soil Clean-Up Levels Presented in March 1988 ROD*

The performance standards of 50 µg/kg for the four indicator organic compounds presented in the March 1988 ROD were neither ARARs nor risk-based standards. The RPs believe that those standards are specific to the SVE system and that they do not have any legal significance with respect to the remedial alternatives being considered in this FFS. Also, the 50 µg/kg level was established for the protection of ground water, which is not appropriate because of the extensive presence of DNAPL in bedrock. Thus, the performance standards are not ARARs, and will not be considered in this FFS.

2.2.3 *Location-Specific ARARs/TBCs*

A screening of location-specific ARARs was completed in accordance with EPA's RI/FS Guidance (EPA, 1988).

2.2.3.1 *Federal ARARs*

There are no location-specific Federal ARARs for the proposed lagoon area soils remedial action. The lagoon area is not located within the 100-year floodplain, designated wetlands and historic preservation districts, wilderness and wild life refuge areas, or areas protected for endangered species. Furthermore, the proposed remedial actions in the lagoon will not impact any Federal designated water bodies such as scenic rivers or wetlands.

2.2.3.2 *State ARARs*

Most of the State ARARs associated with flood plain management, wetlands protection and protection of scenic rivers, etc. are neither applicable nor relevant and appropriate for the lagoon area remediation for the reasons discussed in above paragraph.

Pennsylvania Hazardous Waste Facility Siting regulations (Subchapter F-25 PA Code §§ 75.401-405): These regulations provide criteria for siting hazardous waste treatment and disposal facilities. Although CERCLA remedial actions are exempt from these regulations, the requirements may be relevant and appropriate if a new facility for treatment and/or disposal of hazardous waste is constructed. The Pennsylvania Hazardous Waste Facility Siting regulations identify areas where a facility would not be permitted, and criteria which identify environmental, social, and economic factors which may affect the suitability of the site.

Local Zoning Criteria of Upper Merion Township: These criteria will be considered as potential TBCs.

2.2.4 Potential Action-Specific ARARs/TBCs

A screening of action-specific ARARs was completed for the proposed remedial action of the lagoon area soils. The Federal and State action-specific ARARs identified for the lagoon area are listed in Table 2-1. This list includes only the broad general categories of action-specific requirements. Where appropriate, action-specific ARARs associated with each remedial activity are more fully discussed in Section 3 of this FFS as part of the detailed evaluation of each remedial alternative.

2.2.4.1 *Federal Action Specific ARARs*

RCRA Subtitle C: The RCRA requirements of 40 CFR parts 260, 261, 263 and 264 are not considered applicable to the lagoon area soils because all disposal activities took place prior to 1980. The RCRA requirements are only applicable to hazardous waste disposal activities conducted after 1980. However, since many of the constituents in the lagoon area soils are RCRA-listed waste (F003, F005, F039 and K017), some of these requirements (as discussed below) are considered to be relevant and appropriate. Requirements that are not relevant and appropriate to the proposed actions for the lagoon area soils will not be considered as ARARs.

The closure and ground water components of 40 CFR part 264 subpart F are not considered to be ARARs for the lagoon area soils. For example, ground water is being addressed as a separate operable unit, hence the ground water monitoring requirements are not considered to be an ARAR for remediation of the lagoon area soils. Also, it is not appropriate to develop a closure plan for the lagoon area soils with the intention of ground water protection as per the requirements of 40 CFR part 264.302 and 264.310, since the contribution of lagoon area soils to ground water contamination is insignificant (the widespread presence of DNAPLs in the bedrock is the major cause of continued ground water contamination). The requirements provided in parts 264.302 and 264.310 will not alter this condition and improve the ground water quality. Therefore, the closure requirements within 40 CFR part 264 designed to protect the ground water will not be considered as an ARAR for the lagoon area soils. Instead, a hybrid closure which allows the inclusion of site-specific conditions will be considered. In the March 1988 ROD, EPA had determined that hybrid closure was potentially relevant and appropriate for the lagoon area soils.

The other broad categories of action-specific ARARs for the lagoon area soils include the requirements of Clean Air Act (CAA) and Occupational Safety and Health Act (OSHA).

2.2.4.2 *State Action-Specific ARARs*

The RCRA equivalent of State requirements are evaluated in the same manner as the Federal ARARs. Refer to the discussion in the previous section, and Table 2-1.

The other broad categories of State action-specific ARARs include the Pennsylvania Air Pollution Control Act and the erosion and sedimentation control program.

Table 2-1 Potential Action-Specific ARARs

Federal Action-Specific ARARs

Citation	Requirement	Status	Comments
40 CFR Part 261-264 [1] RCRA Subtitle C	Standards for identifying, treating, storing, and disposing of hazardous waste.	Some portions are relevant and appropriate.	These requirements are not applicable as the disposal took place prior to 1980. However, some portions are relevant and appropriate because lagoon soils are contaminated with RCRA-listed waste (F003, F005, F039 and K017).
40 CFR Part 264 Subpart F 264.92, 264.95, 264.96, 264.97	Standards for ground water monitoring as a part of post-closure requirements.	Not an ARAR for lagoon area soils.	Ground water is being addressed as separate operable unit.
40 CFR Parts 264.302-264.310	RCRA Subtitle C closure, and post-closure requirements.	Not an ARAR for lagoon area soils.	Provisions for design and operation of new facilities only.
40 CFR Part 268	Standards for land disposal restrictions.	Applicable for off-site disposal options only.	Land disposal restrictions apply to RCRA-listed or characteristic hazardous wastes. The lagoon soils are RCRA listed waste. However, LDRs would not apply for on-site disposal after treatment per CAMU rules.
40 CFR Parts 1 through 99 Clean Air Act, National Ambient Air Quality Standard (NAAQS)	Requirements for emissions resulting from treatment facilities.	Relevant and appropriate.	Typically administered by State Agencies. May be relevant and appropriate for treatment technologies with emissions.

1 Some parts are not relevant and appropriate.

Table 2-1 Potential Action-Specific ARARs (Cont'd)

Pennsylvania Action-Specific ARARs

Citation	Requirement	Status	Comments
40 CFR Parts 1 through 99 Clean Air Act, National Ambient Air Quality Standard (NAAQS)	Requirements for emissions resulting from treatment facilities.	Relevant and appropriate.	Typically administered by State Agencies. May be relevant and appropriate for treatment technologies with emissions.
Pa. Hazardous Waste Regulations, 25 Pa. Code, Chapter 260-270 [1]	Pennsylvania regulations for hazardous waste management including identification/storage, treatment and disposal.	Some portions are relevant and appropriate.	Not applicable because no disposal for hazardous waste since 1980. However, some portions are relevant and appropriate because lagoon soils are contaminated with hazardous waste.
25 Pa. Code, Chapters 264.302 to 264.310	Standards for closure and post-closure of hazardous RCRA Subtitle C landfills.	Not an ARAR for the lagoon area soils.	Provisions for the design and operation of new facilities only.
Pennsylvania Air Pollution Regulations 25 Pa. Code, Chapter 121-143	Regulates air emissions for remedial actions. Provides for the control and prevention of air pollutants and guidance for the design and operating of air pollution from stationary sources, consistent with Clean Air Act.	Applicable.	These regulations may be applicable to remedial actions that include air emissions.
25 Pa. Code, Chapter 102.1	Requirements for control of soil erosion/sedimentation resulting from earth moving activities.	Applicable.	Applicable for earth moving actions at lagoon area.
25 Pa. Code, Chapters 287 & 299 Residual Waste Regulations	Requirements for identification, transportation, storage, treatment, and disposal of residual wastes.	Applicable.	These regulations may be applicable for the handling and disposal of some waste materials generated during remediation.

1 Some parts are not relevant and appropriate.

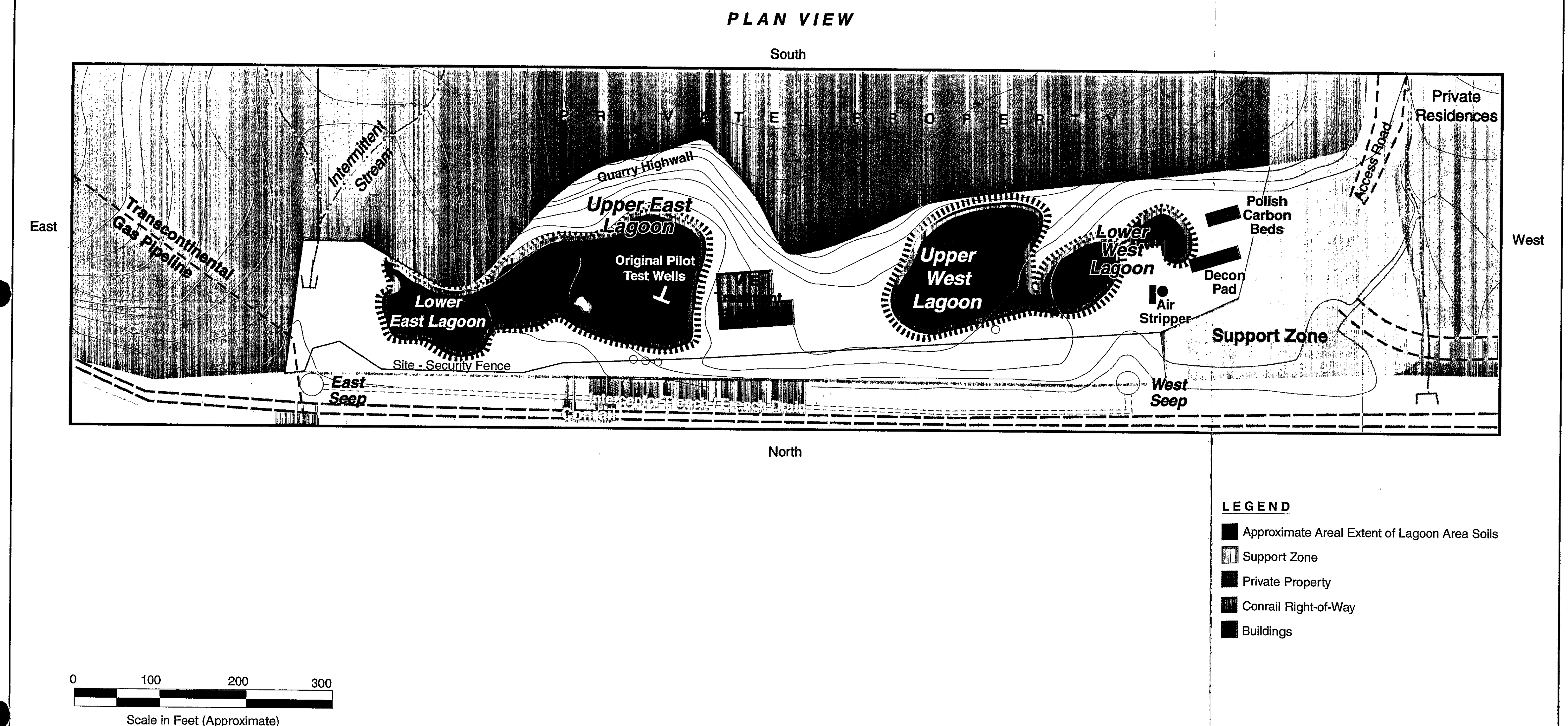
2.3 CHARACTERIZATION OF LAGOON AREA SOILS

The lagoon area of the Tyson's Site is naturally subdivided by topography, soil characteristics and contaminant concentrations into four separate areas which are referred to as the lower east lagoon, upper east lagoon, upper west lagoon, and lower west lagoon, as depicted in Figure 2-1. It is believed that the former lagoons were originally quarry pits which were filled with various layers of soil and rock between periods of liquid waste disposal. The lower east and lower west lagoon areas generally exhibit lower VOC concentrations and thinner zones of unconsolidated, unsaturated soils than the upper east and upper west lagoon areas. The extreme eastern portion of the lower east lagoon area has very low VOC concentrations, and is believed to have been affected by migration of soil contaminants from the former lagoon areas through surface runoff, rather than direct deposition of wastes. Additionally, the existing SVE system support zone at the western end of the site is characterized as uncontaminated.

Based on the estimated natural ground water level in the lagoon area (Figure 1-4), a portion of the contaminated soils are below the natural ground water level. Considering the grain size of the soils encountered in the lagoon area (i.e., primarily silty sands and silty gravels), the thickness of the saturated capillary fringe above the water table has been estimated as approximately 4 feet (Lambe and Whitman, 1969). For purposes of this FFS, however, a saturated capillary fringe thickness of two feet has conservatively been assumed. As a result of these estimates and assumptions, the top of the saturated zone in the lagoon area ranges from 4 to 12 feet below ground surface. Additionally, bedrock is very close to the ground surface at several places within the lagoon area.

Since the completion of the initial RI for the lagoon area soils, a number of soil volume estimates have been made based on a variety of different assumptions and considerations. The total volume of soil within the lagoon area has recently been estimated as approximately 41,100 cubic yards, as presented in Appendix A (TerraVac Site Characterization Report). This estimate includes all lagoon area soils (i.e., from the ground surface to the top of bedrock) north of the quarry high wall and within the exclusion zone fence as shown on Figure 2-1. Of this total, approximately 13,200 cubic yards has been estimated to be within the saturated zone, leaving a total unsaturated soil volume of approximately 27,900 cubic yards.

Figure 2-1
Former Lagoon Locations
Tyson's Site
Focused Feasibility Study



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The distribution of contaminants throughout the lagoon area soils is highly variable. For example, significantly higher contamination zones and isolated DNAPL areas are not clearly definable because of the initial waste disposal practices and the heterogeneous lagoon area soils. However, general areas of similar VOC concentration levels can be estimated from previous sampling events, such as was done for the VOC isoconcentration map presented in Appendix A. Based on previous VOC mass estimates (ERM, 1989 and Appendix A), the total mass of VOCs originally associated with the lagoon area soils is estimated as approximately 400,000 pounds, of which approximately 200,000 pounds has been removed by the SVE operation as discussed in Section 1.4 of this FFS.

2.4 *IDENTIFICATION AND SCREENING OF POTENTIAL REMEDIAL TECHNOLOGIES*

A number of potentially applicable technologies for remediation of the lagoon area soils have been evaluated over the last three years, with levels of effort ranging from paper studies to pilot-scale experimentation. Some of these technologies have been retained for further consideration, while others have been eliminated.

The potentially applicable technologies described in this section can be broadly classified into the following categories (commonly referred to as general response actions):

1) **Institutional Controls** - implementation of institutional controls such as security fences, barriers and/or other indirect methods of reducing exposures to site hazards;
2) **Containment** - physical isolation of wastes and contaminated media;
3) **Removal/Excavation** - physical removal of contaminated media to facilitate treatment and/or disposal;
4) **In-Situ Treatment** - using physical, chemical or biological means to reduce contaminant concentrations in-situ (i.e., without excavating soils);
5) **Ex-Situ Treatment** - on-site or off-site treatment of excavated material to remove and/or destroy contaminants; residues can be disposed of off-site or backfilled on-site.

This document provides a summary of technologies considered according to the following outline:

1) reason(s) for deciding to investigate the technology, including potential advantages and disadvantages;
2) description of evaluation (paper study, lab study, etc.);
3) discussion of key findings from the study; and
4) analysis of results, including the decision to retain or reject the technology.

The identification and screening of technologies based on the criteria of effectiveness, implementability, and cost, for each of these general response actions is presented in the following subsections.

2.4.1 Institutional Controls

Institutional controls reduce potential exposure to site contaminants by restricting site access and potential future uses of the site. Institutional actions include fencing, deed restrictions and property control.

2.4.1.1 Fencing

Reasons for Consideration: A security fence provides an easily implemented, and effective method for restricting entry into areas of concern. Thus, fencing decreases the potential for exposure to contaminants or damage to on-site storage or containment structures. Periodic inspection and maintenance is required to maintain the integrity of a fence. Many remedial alternatives will include a security fence as part of a comprehensive remedy.

Evaluation Conducted: Review of literature and previous FS Reports.

Results of Evaluation: Access to the lagoon area of the Tyson's Site is currently restricted by a chain-link security fence on the north, east and west sides. Access from the south is restricted to a lesser degree by a wooded quarry high wall and temporary construction fence. Additional fencing (i.e., along the south side) and upgrading of the existing fence may be required to further restrict access to the lagoon area. A gate and lock will provide controlled access to authorized personnel.

Decision: Many remedial alternatives will include a security fence as part of a comprehensive remedy. Therefore, this method will be retained and included in the development of remedial alternatives for the lagoon area.

2.4.1.2 *Deed Restrictions*

Reasons for Consideration: Deed restrictions place legal limitations on future use of the property. These restrictions prohibit future uses of the property that could result in increased exposure to site-related contaminants (e.g., intrusive activities, well installation, excavation, etc.). The established boundaries and approved deed restriction language are recorded on the property deed and filed in accordance with applicable laws in the office of the Recorder of Deeds for Montgomery County, and any other offices as applicable where land ownership and transfer records are maintained for real property.

Evaluation Conducted: Review of literature and previous FS Reports.

Results of Evaluation: Deed restrictions can be effective in reducing the potential for disturbance of contaminated media or use of contaminated ground water. In particular, long-term remedial actions expected at the lagoon area will require a deed restriction at least until the completion of such remedial actions. Deed restrictions can be easily implemented if the property owner agrees to such action, but their effectiveness is dependent upon continued enforcement. A more detailed evaluation of potential future land uses and the need for deed restrictions is presented in Attachment B of the Exposure Assessment Memorandum which was submitted to the EPA on 14 July 1994.

Decision: Deed restrictions will prohibit future uses of the property that could result in increased exposure to site-related contaminants (e.g., intrusive activities, well installation, excavation, etc.). Thus, this remedial technology is retained for inclusion in all remedial alternatives.

2.4.1.3 *Property Control*

Reasons for Consideration: Control of the property by the RPs or their agents by obtaining an easement or easements to the areas of concern will permit the performance of various remedial activities without limiting the owner's right to the property. This action eliminates the potential difficulties of implementing or enforcing deed restrictions in case the property owner is not willing to cooperate. If the appropriate easements can be acquired, appropriate deed restrictions and security measures can be implemented to maintain the lagoon area in a manner consistent with the on-going site-wide remediation activities.

Evaluation Conducted: Review of literature and previous FS Reports.

Results of Evaluation: The effectiveness and implementability of this action are similar to those of deed restrictions. This action allows easier implementation of deed restrictions and greater control of site utilization.

Decision: Easements can be a reliable method of institutional control, and are retained for consideration as part of the remedial alternatives. An Easement Agreement with the owner of the property on which the lagoons are located has already been secured for the implementation of remedial actions. Securing additional easements for adjacent areas as needed for site remediation is in progress. An additional discussion of this issue is presented in Attachment B of the 14 July 1994 Exposure Assessment Memorandum.

2.4.2 *Containment*

Containment technologies reduce the potential for direct contact exposure to site-related contaminants and the potential for migration of contaminants through erosion and surface water infiltration by physically isolating the contaminated media or wastes. The primary function of containment technologies for the Tyson's lagoon area soils is to reduce VOC emissions to the atmosphere.

2.4.2.1 *Soil Cover*

Reasons for Consideration: A soil cover consists of a soil layer about 18 to 24 inches thick placed over the area of concern to prevent direct contact with contaminated media, and to a lesser extent reduce surface water infiltration. A soil cover includes a 6 inch topsoil layer that is vegetated to minimize erosion by surface water and wind. Occasionally, a soil cover may be constructed with a gravel layer for erosion control, traffic, or other activities.

Evaluation Conducted: Review of literature (EPA, 1985 and 1991b).

Results of Evaluation: A soil cover eliminates direct contact with contaminated soil, although it cannot control surface water infiltration or VOC emissions to the degree of other caps with impermeable layers or barriers.

Decision: Since a soil cover prevents direct contact exposures and provides some control of infiltration and VOC emissions, it is retained for further consideration.

2.4.2.2 *Clay Cap*

Reasons for Consideration: A clay cap consists of a compacted, low-permeability clay layer with a vegetated soil cover. For the lagoon area, a clay cap is intended to prevent direct contact with contaminated soil and to reduce VOC emissions. A clay cap will also minimize the infiltration of rainwater into the contaminated soil and subsequent leaching of contaminants into ground water. If necessary, VOC emissions could be further controlled by an active venting system. A clay barrier is more effective than a flexible membrane liner (FML) at controlling VOC emissions. FMLs are not considered in this FFS.

Evaluation Conducted: Review of literature (EPA, 1979, 1985 and 1991b) and previous FS Reports.

Results of Evaluation: A clay cap eliminates the potential for direct contact exposure to contaminated soil and migration of contaminants by erosion. It will also be effective in restricting VOC emissions. By placing the clay layer in a relatively dense and moist condition, the air-filled porosity of the clay layer can be minimized, thereby minimizing VOC vapor migration. If necessary, VOC emissions could be further reduced by venting the clay cap. Capping is commonly performed when waste volumes are large and the associated risk can be adequately controlled by the cap, or when excavation and removal of the waste is not practicable due to potential hazards or unrealistic costs (EPA, 1991b).

Decision: A clay cap will effectively control VOC emissions at a moderate cost. This type of cap has been installed at numerous waste disposal and contaminated sites and is readily implemented through standard engineering and construction services. Thus, a clay cap is retained for consideration in the development of remedial alternatives.

2.4.2.3 *Composite Barrier Cap*

Reasons for Consideration: A composite barrier cap refers to a cap that includes more than one barrier layer, where a barrier layer is generally regarded as a compacted clay layer or a geomembrane liner. This type of cap typically consists of a clay layer, a geomembrane liner, a vegetated soil cover and other components. This type of cap can prevent direct contact exposure to contaminated soil, control VOC emissions and reduce surface water infiltration. If necessary, VOC emissions could be further controlled by venting of the composite barrier cap.

Evaluation Conducted: Review of literature (EPA, 1979, 1985, 1989, 1991a and 1991b) and previous FS Reports.

Results of Evaluation: A composite barrier cap eliminates the potential for direct contact with contaminated soil and migration of contaminants by erosion. The clay component of this type of cap is effective in restricting VOC emissions, although the effectiveness of the geomembrane liner at restricting VOCs is much less. The additional layers result in this type of cap being more costly than a clay cap.

Decision: This type of cap has been installed at numerous waste disposal and contaminated sites and is implementable with standard construction services. Because a clay cap is considered to be as effective as a composite barrier cap at preventing direct contact exposure and restricting VOC emissions, and a clay cap is less expensive than a composite barrier cap, a composite barrier cap is eliminated from further consideration. The only additional benefit of the composite barrier cap is some slight additional protection against surface water infiltration, which is not a goal for the lagoon area.

2.4.2.4 Wet Soil Cover

Reasons for Consideration: This containment technology maintains a nearly-saturated soil layer over the lagoon area soils to provide VOC emission control. By applying water to a compacted soil layer through an irrigation system, saturated or nearly saturated conditions can be maintained throughout the contaminated soil column over the lagoon soil. Because aqueous-phase diffusion is several orders of magnitude less than vapor-phase diffusion for the constituents of concern in the lagoon area soils, maintaining the soil in a wet or saturated condition will virtually eliminate VOC emissions through the soil cover above the wet barrier. Downward movement of irrigation water will also act to keep the contaminants' aqueous-phase-diffusion front from reaching the surface.

Evaluation Conducted: In-house review, engineering assessment.

Results of Evaluation: By restricting vapor-phase diffusion, this technology has the potential to effectively eliminate VOC emissions through the cover. The relatively small volume of water (5 gpm or less) to be applied to the subsurface is not anticipated to cause contaminant migration beyond the current contaminated areas.

Decision: Because of its potential effectiveness and low cost, this technology is retained for further consideration.

2.4.2.5 *Vertical Subsurface Barriers*

Reasons for Consideration: Vertical barriers (e.g., slurry walls, grout curtains, sheet piling) are containment methods intended to restrict the lateral migration of ground water and contaminants into and/or out of a zone of contamination. Based on the presence of bedrock at the lagoon area, grout curtains and shallow slurry walls are the only practical means available for creating a vertical barrier wall around the perimeter of the lagoon area soils.

Evaluation Conducted: Review of literature (EPA, 1985 and 1991b); SVE dewatering well shutdown and ground water recovery test (March 1995).

Results of Evaluation: Based on the absence of seeps during the SVE shutdown, the existing seep collection system effectively controls lateral migration. Although this technology is feasible, its application is not necessary.

Decision: Lateral migration of water through the lagoon area soils is not anticipated to be a significant concern at this point in time. Thus, this technology has not been retained for the development of alternatives.

2.4.2.6 *Bottom Sealing*

Reasons for Consideration: Bottom sealing may be used to protect backfilled clean soil from aqueous and/or vapor-phase recontamination. This may be considered to be bedrock or soil sealing as discussed in Appendix E. For treated or clean soils backfilled within the saturated zone, a barrier system installed on the bedrock surface before backfilling of the treated or imported clean soil is considered as a potential method to seal the bedrock and to prevent the seepage of contaminated ground water into the treated or clean soil. Similarly, a clay or other impermeable layer constructed prior to the backfilling of treated or imported clean soils in the unsaturated zone may restrict upward VOC vapor migration from the underlying contaminated soils. Potential bedrock sealing technologies include grouting, clay- and bentonite-based barriers, flexible membrane liners (FMLs), and various cement- and bituminous-based coatings.

Evaluation Conducted: Review of literature (EPA, 1985 and 1991b), engineering assessment (Appendix E).

Results of Evaluation: To achieve effective containment for the lagoon area soils, the entire lagoon boundary (bottom and sidewall) would have to be sealed. Similar barrier systems have been used successfully in the past to prevent leachate releases from landfills. However, these systems are generally used to control and contain the downward migration of fluids, rather than to prevent upward or lateral flow of ground water. Based on previous applications, barriers can effectively control or reduce seepage, but cannot totally eliminate it. Although seepage reduction is typically acceptable for most applications, minor seepage into soils placed within the saturated zone means that aqueous recontamination of such clean soils cannot be prevented in the long-term. Clay or similar barrier layers placed in the subsurface could be effective for the control of VOC emissions through unsaturated zone soils, although inspection and maintenance of such a system several feet below the ground surface would be difficult, and the advantages over a surface barrier are questionable.

Decision: Consideration of this technology is for the prevention of recontamination. A detailed discussion and decision is presented in Section 2.5.

2.4.2.7 *Hydraulic Controls*

Reasons for Consideration: Hydraulic controls can be used to prevent the flow of clean ground water through zones of contaminated soil, or to capture and contain contaminated ground water to prevent contaminant migration. Such controls could also be considered to prevent contaminated ground water from intruding into zones of clean soil placed within the saturated zone. Pumping wells and subsurface drains are typical methods for achieving hydraulic control. For the Tyson's Site, hydraulic controls including pumping wells and a french drain are currently being used to control the migration of contaminated ground water.

Evaluation Conducted: Review of literature (EPA, 1985).

Results of Evaluation: Measures to control ground water passing through the lagoon area soils will not result in improved ground water quality due to the widespread presence of DNAPL in the bedrock. Also, the use of hydraulic controls to prevent aqueous-phase recontamination of clean soils backfilled into the saturated zone will not be effective because any temporary shut-down or failure of the system would result in recontamination of the soil.

Decision: The site conditions preclude the potential benefits of additional hydraulic control measures to address the lagoon area soils. As appropriate, however, the existing and other minor hydraulic control measures are considered in the development of remedial alternatives.

2.4.3 *Excavation*

Reasons for Consideration: Excavation refers to the physical removal of contaminated media, and is commonly required to facilitate ex-situ treatment or disposal actions. Contaminated soils can be excavated using a backhoe-type excavator or similar equipment. If required, excavated soil will be stockpiled, screened, and handled prior to treatment or disposal. During excavation and handling, the disturbance of contaminated soils will result in fugitive VOC emissions and potential direct contact exposure.

Evaluation Conducted: Review of literature (EPA, 1985) and previous FS Reports, engineering assessment.

Results of Evaluation: Excavation will increase potential human health hazards as a result of increased VOC emissions and dust generated from the disturbed soil. In addition, excavation increases the potential for direct contact with contaminated soils by on-site workers. As a result, emission control and site worker protection will be required and will involve a high degree of engineering and management controls.

Decision: Although the excavation and handling of the lagoon area soils will result in increased exposure risks during remedy implementation, excavation is retained for the development of ex-situ treatment and/or disposal alternatives. More detailed discussions and evaluations of excavation are presented in later portions of this FFS.

2.4.4 *Disposal*

Disposal technologies provide secure, permanent containment of contaminated media or wastes. Thus the potential for exposure to or migration of contaminants is minimized.

2.4.4.1 *Off-Site Landfill*

Reasons for Consideration: This technology involves the excavation, transportation, and disposal of untreated soils, treated soils, or treatment residues at an approved off-site landfill. An off-site landfill could provide for the secure containment of contaminated materials, thereby restricting the migration of constituents into the environment and reducing risk.

Evaluation Conducted: Review of literature (EPA, 1985) and previous FS Reports.

Results of Evaluation: Excavation of soils will be required prior to disposal, and DOT permits (pertaining to labeling, placarding, packaging, spill reporting, manifesting and record keeping) will be required for the transportation of soil to a permitted facility. The lagoon area soils contain certain materials which are classified as listed hazardous wastes under RCRA. Current RCRA regulations (i.e., Land Disposal Restrictions or LDRs; 40 CFR 268) prohibit the land disposal of such soils unless the established treatment requirements are met. Off-site landfill disposal of soils that contain concentrations below the treatment standards, or that have been treated to below the treatment standards, is feasible.

Decision: Off-site landfilling may be appropriate for excavated and/or treated soils that meet the treatment standards. Thus, this technology is retained for further consideration.

2.4.5 In-Situ Treatment Technologies

In-situ treatment technologies reduce the toxicity, mobility, or volume of contaminated media or wastes, without removing that medium of concern. Thus, the treated material remains in place during and after such treatment. Although in-situ treatment technologies cannot generally achieve a high level of treatment efficiency, they may be sufficient to reduce the site-related risks to an acceptable level. In-situ technologies are often favored when ex-situ technologies require massive disturbance of the contaminated material, creating short-term risks. Examples of in-situ treatment technologies include vacuum extraction, stabilization, soil flushing, and bioremediation.

2.4.5.1 Soil Vapor Extraction

Reasons for Consideration: Vacuum extraction, or soil vapor extraction (SVE), removes VOCs in a vapor phase by withdrawing air from the pore spaces of contaminated soil. Vacuum extraction has shown effectiveness for the removal of VOCs from some soil matrices under certain conditions. Vacuum extraction is most appropriate for homogeneous soils with relatively high permeabilities and relatively low moisture contents.

Evaluation Conducted: Literature review (EPA, 1992), pilot tests and five years of SVE operation at the Tyson's Site.

Results of Evaluation: Over the past five years of operation, the Tyson's Site SVE system has removed a significant amount of VOC mass from the lagoon area soils. It is estimated that approximately 50% of the total VOC mass present within the lagoon area soils at the start of SVE had been removed as of July 1994. The SVE system has preferentially removed the more volatile and more mobile constituents.

VOC removal rates have dropped from 5,000 pounds per month in 1988 to less than 325 pounds per month in 1994. It has been concluded that the established performance standards will not be achieved. Limiting factors include soil heterogeneity, mass transfer constraints, presence of DNAPLs and high soil moisture content.

Decision: SVE is unlikely to result in any further significant decreases in VOC concentrations or mass. Thus, soil vapor extraction is not retained for further considerations. However, the existing SVE equipment and facilities may be used to support other technologies involving vapor extraction and treatment.

2.4.5.2 *In-Situ Volatilization with Heat and Mixing*

Reasons for Consideration: This technology involves a combination of in-situ mixing and heating of lagoon area soils with vapor extraction. Heating enhances the volatilization of contaminants (by increasing the vapor pressure of the contaminants), thereby increasing the rate of mass transfer from the soil phase to the gas phase. Hot air and/or chemical reagents such as lime can be used to enhance volatilization by direct heating (hot air and/or steam) or reaction with soil moisture. In addition, soil mixing in-situ provides a more homogeneous distribution of reagents and contaminants, increases permeability to air flow, and exposes a greater proportion of the contaminant mass to the gas phase. In-situ mixing can be accomplished with auger-type or similar mixing equipment which is commercially available. VOC emissions collection and subsequent treatment are critical to minimizing implementation risks.

A variation of this technology utilizes a modified trenching machine to agitate, mix and heat the contaminated soils in-place, and remove VOCs in one step. This unit is moved across the site until all of the soils are treated to the established level. The VOC off-gas can be treated using existing vapor-phase carbon adsorption or similar treatment equipment.

Evaluation Conducted: Bench-scale laboratory screening studies using lime addition and hydrogen peroxide injection (Ciba-Geigy, 1993a); on-site pilot mixing studies (Feenstra and ERM, 1993); and engineering evaluations. A more detailed discussion and evaluation of this technology is presented in Appendix B (In-Situ Heating and Mixing).

Results of Evaluation: As discussed in Appendix B, evaluation of this technology has included the performance of detailed bench- and pilot-scale testing. Relatively high TCP removal efficiencies were achieved in the laboratory using lime addition and mixing, although mixing without lime was also found to result in substantial TCP reductions. Hydrogen peroxide addition resulted in removal efficiencies somewhat less than those achieved with lime addition. Other means of volatilization such as hot air injection may be able to enhance volitilization at a lower cost. VOC capture efficiencies associated with these methods are of concern, as significant fugitive emissions of VOCs may be associated with such processes. Although mixing without chemical addition or heat was found to be effective in removing VOCs from the soil, the treatment time required was relatively long. The presence of significant boulder zones will also complicate the implementation of in-situ mixing of the lagoon area soils.

Decision: Auger-type in-situ soil mixing and heating technologies suffer from numerous shortcomings and they are not retained for further consideration. By contrast, the modified trenching machine is markedly superior in relation to the auger technology's shortcomings. The principal shortcoming of the modified trenching machine is its lack of adequate means to prevent fugitive emissions.

Until and unless a field demonstration of the modified trenching machine is performed at the Tyson's Site, it will not be possible to complete a detailed evaluation of the technology as a full-fledged treatment alternative. If soil treatment is required, the modified trenching machine would be evaluated in a pilot study along with other on-site treatment technologies.

2.4.5.3 *Biological Treatment*

Reasons for Consideration: Biological treatment, or bioremediation, is a process of converting organic constituents to a less toxic or inert substance using microorganisms. Microorganisms present in or added to soil derive energy by oxidizing hydrocarbon compounds, including some toxics. The most common biological treatment processes are based on aerobic or anaerobic bacteria, such as those processes utilized in the treatment of municipal wastewaters.

Evaluation Conducted: Literature review; laboratory study (Ciba-Geigy, 1992).

Results of Evaluation: A number of parameters including pH, temperature, availability of nutrients, and the type and concentration of contaminants influence the effectiveness of biological treatment. Some biological treatment methods have been successful for the treatment of organic contaminants, but the high contaminant levels present in the lagoon area soils are likely to be toxic for many microorganisms. For example, there are no known examples of bioremediation processes that can degrade 1,2,3-trichloropropane (TCP) at significant rates. A laboratory study of this process indicates that biotreatment is not effective for TCP at the concentrations found in the lagoon area soils at the Tyson's Site. In this study, attempts were made to obtain or develop cultures from soil samples that could degrade TCP. Aerobic and anaerobic conditions were tested under ideal laboratory conditions, all unsuccessfully. Other organic substrates were also introduced in unsuccessful attempts to stimulate biodegradation through cometabolism.

Decision: Because this technology has proven in lab studies to be ineffective for the treatment of the existing concentrations of a key contaminant at this site, it is not retained for the development of remedial alternatives for the lagoon area soils.

2.4.5.4 *Soil Flushing*

Reasons for Consideration: Soil flushing is an in-situ remediation technology in which contaminants are extracted from the soil matrix by means of application of treatment fluids and collection of the liquids containing the contaminants. Collected fluids are treated and/or disposed at the surface. Treatment fluids for removal of hydrophobic organics such as those in the lagoon area soils may include surfactants, solvents, or co-solvent mixtures.

The mechanisms for removal of organic contaminants from the soil matrix include solubilization, desorption from particle surfaces, or mobilization of DNAPLs by means of emulsion formation or reduction of surface tension leading to a reduction of resistance to flow.

Evaluation Conducted: Literature review (EPA, 1985, 1991b, 1992, 1993a and 1993b).

Results of Evaluation: Soil heterogeneities are expected to inhibit the effectiveness of soil flushing. Also, there is potential for the flushing solutions to cause remobilization of DNAPL and subsequent releases to the underlying bedrock.

Soil flushing produces a liquid waste stream that requires treatment. The treatment process appropriate for this waste stream depends upon the nature of the treatment fluids. The use of solvents or surfactants could require the recycling of the treatment fluids to control usage and cost. Mass transfer with soil flushing is unlikely to perform as well as other in-situ treatment technologies; cleanup times are also likely to be longer.

Decision: Soil flushing using chemical solvents and surfactants is eliminated from further consideration because of its questionable removal effectiveness, relatively high cost, and lack of added benefits over more cost-effective options.

2.4.5.5 *In-Situ Oxidation*

Reasons for Consideration: In-situ chemical destruction techniques are innovative technologies in which chemicals are added to the subsurface for the purpose of causing chemical reactions that lead to the destruction of or reduction in toxicity of contaminants. For organic contaminants such as those in the lagoon area soils, the applicable chemical processes are redox processes, most notably oxidation. Chemical additives that may be used to oxidize such compounds include hypochlorites, hydrogen peroxide, or permanganate. Although the use of all of these additives has been investigated for other contaminated sites, no successful operating or completed full-scale systems for the detoxification of organics such as those in the lagoon area soils have been identified.

Evaluation Conducted: Literature review (EPA, 1992), Ciba-Geigy 1993 research.

Results of Evaluation: As in soil flushing, chemical destruction technologies are sensitive to heterogeneities in site conditions. Direct oxidation of DNAPL in the subsurface has not been satisfactorily demonstrated either in the field or the laboratory. Control and recovery of treatment fluids, reactants, reaction byproducts and unreacted contaminants will be technically challenging.

In-situ oxidation may result in the production of reaction products that are themselves of environmental concern. This is particularly true for the use of chlorine containing oxidants such as calcium or sodium hypochlorite (bleach), which may lead to the production of a variety of chlorinated organic compounds in the subsurface. There is expected to be numerous competing reactions occurring in the subsurface as the result of the in-situ addition of oxidizing compounds. Competing reactions will reduce the efficiency of the destruction of the targeted compounds. For example, hydrogen peroxide, may preferentially oxidize sewage sludges and natural organic matter in the soils, change the oxidation states of metals such as iron and manganese in the soil, or dissociate to form oxygen and water so that it is not available for oxidation of contaminants. Addition of strong oxidants may lead to changes in soil properties which negatively impact the performance of the treatment technology.

In-situ oxidation technology will result in the production of a contaminated fluid that must be collected and treated prior to disposal. Although the option to recycle treatment fluids exists and is generally favored by the economics of the process, contaminants and undesirable byproducts in the effluent must be treated or removed. A system different than that already in place at the site will be required.

The applicability of in-situ oxidation is questionable, primarily due to concerns over the potential to produce undesirable reaction byproducts, lack of appropriate effluent treatment facilities at the site, and effectiveness concerns.

Decision: Because of concerns regarding the generation of potentially harmful materials in the subsurface, and because this technology provides little or no benefits over more proven and cost-effective technologies, it is not retained for the development of remedial alternatives.

2.4.5.6 Stabilization

Reasons for Consideration: Stabilization involves mixing additives with the soil for the purpose of decreasing the mobility of contaminants. The mechanisms by which reduction of mobility is achieved include a reduction in soil permeability and chemical or physical encapsulation of contaminants. Stabilization materials include cement-based, silicate-based (pozzolanic), thermoplastic, organic polymer, and various proprietary compounds.

Evaluation Conducted: Review of literature (EPA, 1985, 1991b and 1992).

Results of Evaluation: These technologies do not destroy or remove significant amounts of contaminants, but serve to reduce their mobility, thus reducing potential exposure to the contaminants. Waste materials and/or affected soils can be mixed in-place with soil mixing systems. Off-gases from the mixing process must be controlled. Although readily available, stabilization methods are not considered to be applicable for soils contaminated primarily with high levels of VOCs (EPA, 1991b).

Decision: This technology will not be considered further because of the technical uncertainties and limitations discussed above, and limited benefits.

2.4.5.7 *In-Situ Soil Heating/Vitrification*

Reasons for Consideration: In-situ soil heating/vitrification, as discussed here, refers to two technologies: 1) In-Situ Vitrification (ISV), and 2) Radio Frequency (RF) soil heating. ISV uses an electric current which is sent through electrodes inserted in the ground to generate extremely high temperatures which melt soil or sludge. This heating process is used to remove and/or destroy organic contaminants and trap inorganic contaminants within the resulting glass-like, vitrified mass. RF soil heating is accomplished by inserting tubular electrodes into the contaminated soil or by laying electrodes over the ground surface, and exciting the electrodes with radio-frequency energy to heat the soil. Due to lower operating temperatures, RF soil heating does not melt the soil being treated. In both cases, water vapor and organic gases driven off by the heating processes must be captured and passed through an off-gas treatment system.

Evaluation Conducted: Review of literature (EPA, 1992 and 1993a).

Results of Evaluation: Unfavorable conditions (DNAPL, wet soils, etc.) limit the effectiveness of soil heating at the site. In the literature, the effectiveness of in-situ vitrification is considered questionable due to the entrapment of volatilized gases during soil melting which can later become mobile. RF soil heating has shown some promise during preliminary field tests elsewhere, although development of this technology has been slow, but it has not been used for full-scale remediation projects. As with other volatilization processes, fugitive VOC emissions are a concern.

Decision: Based on the discussion above, in-situ soil heating and vitrification are eliminated from further consideration.

2.4.6 ***Ex-Situ Treatment Technologies***

Ex-situ technologies refer to all technologies for soil remediation that require the excavation of soil, treatment of the contaminated soil in a system located either on-site or off-site, and replacement of the treated residue on-site or disposal off-site. Most on-site technologies make use of mobile treatment units. Many of the available systems are considered innovative and limited data exist pertaining to their expected performance for the lagoon area soils.

2.4.6.1 *Ambient Temperature Volatilization*

Reasons for Consideration: Ambient temperature stripping of VOCs from soils may be achieved by aggressive aeration which is achieved through screening, tilling or discing. These operations maximize the rate of volatilization by breaking up the solid materials and increasing contact between the solid surfaces and air.

Evaluation Conducted: Review of literature, engineering evaluation (OHM, ERM experience).

Results of Evaluation: This process has been used effectively to remove VOCs from contaminated soils at a limited number of sites. For relatively sandy soils and relatively volatile compounds, this technology can generally produce reductions in significant VOC concentrations. For lagoon area soils, an altered DNAPL substance (i.e., tarry residue) is likely to remain after aeration. Therefore, the residual VOC concentrations may be quite high. The high moisture content and fine particle sizes are also potential impediments to successful implementation of this process. Volatilized contaminants require proper emission control measures including enclosures with ventilation, vapor collection and treatment, and personnel protection equipment.

Except for VOC emission control, this technology is relatively simple to implement and the unit cost is low to moderate. However, due to the presence of significant boulder zones in the lagoon area, soil pretreatment will be necessary before implementing any of these approaches. If pretreatment is required, the costs of these methods approach those of more effective technologies such as low-temperature thermal desorption (LTTD).

Decision: This alternative will not be considered further due to its limited effectiveness as compared to cost-competitive alternatives.

2.4.6.2 *Ex-Situ Enhanced Volatilization*

Reasons for Consideration: This technology is very similar to the in-situ volatilization processes discussed previously, except that this process includes heating in addition to mixing to facilitate effective VOC removal.

Potentially appropriate ex-situ volatilization equipment has been developed for other projects and may be less costly than other ex-situ technologies.

Evaluation Conducted: Bench-scale laboratory screening (Ciba-Geigy, 1993a) and review of literature.

Results of Evaluation: High TCP removal efficiencies were achieved in controlled laboratory conditions using an ex-situ mixing process. Hot air application increases removal efficiencies. The heterogeneity of the lagoon area soils, as well as the uneven distribution of VOCs may make it difficult to achieve consistently high removal efficiencies. Potentially effective full-scale equipment could be developed for this site. However, detailed testing and evaluation would be required prior to implementation.

Decision: The potentially limited effectiveness, and the need for development and testing make this technology less attractive than other proven technologies. Therefore, this technology is eliminated from further consideration.

2.4.6.3 *Soil Washing/Solvent Extraction*

Reasons for Consideration: This technology is similar in principle to the soil flushing technology, except that solvent extraction (or soil washing) is an ex-situ process involving excavation and treatment in an above-ground treatment system, rather than in-situ. In this process, soil and washing solution are mixed in a vessel to dissolve the contaminant(s) into the solution or to separate the fine fraction of soil which normally contains higher concentrations of contaminants. Treated soil can be backfilled on-site if cleanup standards are achieved, or it can be disposed off-site if it meets the LDR requirements. Residual solvent in the treated soil could also be an issue. Recovered contaminants in the spent solution may require subsequent treatment or disposal. The fine fraction separated from the soil may also require further treatment or disposal. A variety of solvent extraction processes have been developed or are currently under development. Commercial mobile solvent extraction units have limited availability. Treatability studies are typically required prior to implementation of this technology to determine its potential effectiveness and to refine system operating parameters. VOC emission controls will be required during soil processing.

Evaluation Conducted: Review of literature (EPA, 1990, 1992, 1993a, 1993b and 1993c).

Results of Evaluation: Like soil flushing, this process has proven to be effective for the removal of certain organic and inorganic constituents adsorbed onto soils. For the VOCs in the lagoon area soil, however, the effectiveness and cost of soil washing are not comparable to some other technologies.

Decision: Soil Washing/Solvent Extraction is not considered favorable because of its limited benefits over cost-competitive treatment alternatives, limited availability, and need for subsequent treatment and/or disposal of spent wash water and treatment residuals. Therefore, this technology will not be considered for the development of remedial alternatives.

2.4.6.4 *Low Temperature Thermal Desorption*

Reasons for Consideration: LTTD is an on-site remediation process in which excavated soils are screened, mixed and exposed to elevated temperatures below those at which combustion will occur. Contaminants are driven from the soil into a concentrated gas stream that then requires treatment prior to release to the atmosphere. Techniques for treating the contaminant-laden gas stream produced by LTTD include condensation of solvents, gas-phase carbon adsorption or thermal oxidation. The treated soils are returned to the excavated area. This technology should be able to achieve low cleanup levels for the contaminants at the site, depending upon the temperature, retention time within the desorption unit and degree of mixing and heat transfer. Residuals (e.g., condensates and spent activated carbon) from this treatment technology will require further treatment.

Evaluation Conducted: Laboratory screening study (Ciba-Geigy, 1993b), and literature review (EPA, 1992, 1993a and 1993b; ETG, 1993).

Results of Evaluation: Soils with VOC concentrations in the tens of thousands of mg/Kg can be treated to levels below 100 mg/Kg. A number of issues remain to be resolved, including handling of tarry substances that may form during desorption, and appropriate scale-up of time and temperature parameters.

Decision: Based on its proven effectiveness and competitive costs, this technology will be retained for the development of remedial alternatives.

2.4.6.5 *Incineration*

Reasons for Consideration: Incineration is a thermal treatment method which uses high temperature oxidation to degrade waste materials. Byproducts from this process include carbon dioxide, water vapor, ash, nitrous oxide, sulfur dioxide, and hydrochloric acid gases. Air pollution controls are required to treat off-gases to meet air quality standards. Types of incinerators that are commonly used for the remediation of solid waste and soils include rotary-kiln, fluidized bed and infrared incinerators. Excavated soils can be transported off-site for incineration or they can be treated with a mobile incinerator assembled on-site.

Evaluation Conducted: Review of literature (EPA, 1987 and 1992), and vendor discussions.

Results of Evaluation: Incineration has been the most common method of treating high concentration, high toxicity organic wastes in recent years. Off-site and on-site mobile incinerators are available to treat the lagoon area soils. The relatively large volume of contaminated soil to be treated will likely make the costs of mobilization, construction, permitting and operation of an on-site incinerator less than the high costs associated with off-site transportation and incineration of materials. On-site incineration will necessitate feed preparation and prevention of VOC emissions. Also, the tight site space will limit the flexibility of equipment layout.

Although on-site incineration is used to remediate contaminated sites, it has fallen out of favor, primarily due to perceived risks associated with exposure to products of incomplete combustion released to the atmosphere. A few highly publicized examples of poor performance of this technology are the basis for this widely held view. While off-site incineration may address some of the public concerns, the risks of transporting large quantities of contaminated soil to an off-site incinerator have to be evaluated.

Decision: Off-site incineration will be retained for further consideration due to its proven effectiveness for the destruction of organic contaminants. Site constraints and public concern justify elimination of on-site incineration from further consideration at this time.

2.4.7 Summary of Technology Screening

A summary of the technology screening process is presented on Table 2-2. The remedial technologies presented on Table 2-2 that are retained for further consideration are combined into a range of comprehensive remedial alternatives for the lagoon area soils in the next section (Section 2.5) of this FFS.

Table 2-2 Summary of Technology Screening

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
INSTITUTIONAL ACTION:					
Fencing	A chain link security fence to restrict site access.	• Reduces risk of exposure to contaminants by restricting access. • Reduces risk of disturbance by unauthorized intruders.	• Easily implemented. • Periodic maintenance and inspection required to maintain fence integrity.	• Capital: $40,000 to $70,000. • O&M: $7,000 to $10,000 per year.	Retained for further consideration.
Deed Restrictions	Legal limitations placed on future property use to restrict excavation, well installation and other ground disturbances.	• Reduces potential risks from future land use. • Reliability is dependent upon continued enforcement.	• Easily implemented if approved by property owner. • Restrictions are recorded with property deed.	• Capital: $10,000 to $25,000. • No O&M.	Retained for further consideration.
Property Control	Purchase or obtain full control of the property and adjacent areas which may be required to facilitate remediation.	• Allows flexibility in performing various remedial activities. • Provides better control for enforcing deed restrictions.	• Easily implemented if agreed to by property owner.	• Capital: Not Determined • No O&M.	Retained for further consideration.

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Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
CONTAINMENT:					
Soil Cover	A vegetated soil layer about two feet thick placed over the contaminated soils in the former lagoons.	• Prevents direct contact exposure to contaminated soils, and reduces potential for migration of contaminated soils through erosion. • Not effective as other barriers for VOC emission control.	• Equipment, labor and materials are readily available. • Can be easily implemented.	• Capital: $8 to $15 per square yard. • O&M: $4,000 to $7,000 per year.	Retained for further consideration.
Clay Cap	A cap with a low-permeability clay layer and a vegetated soil cover. May include active gas venting.	• Significantly reduces VOC emissions. • Prevents direct contact with contaminated soils. • Reduces surface water infiltration.	• Equipment, labor and materials are readily available. • Can be easily implemented.	• Capital: $30 to $45 per square yard. • O&M: $4,000 to $9,000 per year (not including gas venting and treatment).	Retained for further consideration.
Composite Barrier Cap	A multilayer cap consisting of a low-permeability clay layer, a geomembrane liner, and a vegetated soil cover. May include active gas venting.	• Clay layer effectively controls VOC emissions. • Geomembrane liner reduces surface water infiltration. • Prevents direct contact to contaminated soils.	• Equipment, labor and materials are readily available. • Can be easily implemented.	• Capital: $40 to $60 per square yard. • O&M: $4,000 to $10,000 per year.	Eliminated from further consideration because of limited benefits over clay cap (infiltration reduction is not critical) at a higher cost.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
Wet Soil Cover	A saturated soil layer with an irrigation system as a cover over the lagoon area soils.	• Saturated soil will prevent vapor-phase diffusion, thereby restricting VOC emissions. • Prevents direct contact to contaminated soils.	• Equipment, labor and materials are readily available. • Can be easily implemented, but unknown use for environmental applications to date.	• Capital: $30 to $50 per square yard. • O&M: $15,000 to $30,000 per year.	Retained for further consideration due to its potential effectiveness.
Vertical Subsurface Barriers	Low-permeability vertical subsurface barrier (i.e., grouting and/or slurry walls) to restrict ground water flow into or out of the lagoon area soils.	• Can restrict lateral ground water flow in shallow soils, although flow will still occur through contaminated bedrock at greater depths.	• Construction techniques are common, but require some specialized materials and methods. • High-wall and shallow bedrock will require special consideration.	• Capital: $8 to $25 per square foot of barrier. • O&M: $1,000 to $3,000 per year.	Eliminated from further consideration based on limited benefits.
Bottom Sealing	A barrier system of grout, clay, and or membrane liners to seal the underlying soils and/or bedrock to prevent the seepage of contaminated ground water into the zone of backfilled clean soils.	• Permanent control of seepage is not technically feasible within saturated zone.	• Leak-proof system is not practicable. • Large open excavation area needed to install barrier without joints. • Inspection and maintenance of bottom barrier is not practicable.	• Not determined.	Discussed further in Section 2.5.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
Hydraulic Controls	Hydraulic controls such as horizontal wells and subsurface drains.	• Not reliable for preventing recontamination of treated soils (system shut-down would allow recontamination of soil).	• Horizontal well drilling would require some specialized equipment. • Some hydraulic controls are currently in use at the site.	• Capital: \$50,000 to \$200,000. • O&M: \$50,000 to \$200,000 per year.	Eliminated from further consideration on its own due to limited benefits; minor hydraulic controls will be considered as appropriate.
EXCAVATION:					
Excavation	Site-wide or limited excavation of lagoon area soils to facilitate treatment and/or disposal.	• Required to facilitate treatment and/or disposal. • Increases short-term inhalation and direct contact exposure risks.	• The equipment, labor and materials required for excavation are readily available. • Control of fugitive VOC emissions requires a high degree of engineering and management controls.	• Capital: \$20 to \$40 per cubic yard. • No O&M.	Retained for consideration with treatment and disposal technologies.
DISPOSAL:					
Off-Site Landfill	Excavation, transportation, and disposal of untreated soils, treated soils, or treatment residues at an approved off-site landfill.	• Applicable for treated soils and/or treatment residuals. • Off-site transportation could present potential risks.	• Appropriate landfills are available. • Current regulations would prohibit the disposal of untreated soils from the site unless established treatment requirements are met.	• Capital: \$250 to \$400 per cubic yard, including transportation. • No O&M.	Retained for possible inclusion with treatment technologies.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
IN-SITU TREATMENT:					
Soil Vapor Extraction	Soil vapor extraction (SVE) removes VOCs in a vapor phase by withdrawing air from the pore spaces of contaminated soil; this considers continued operation of the existing system.	• Effectiveness has been less than expected due to unfavorable site conditions. • Removal efficiencies have decreased substantially over time.	• This technology has been in operation at the site for greater than 5 years.	• O&M: \$2 to \$2.5 million per year.	SVE has approached a low asymptomatic limit of mass removal effectiveness, and is eliminated from further consideration.
In-Situ Volatilization (with mixing)	In-Situ mixing and injection of hot air, steam, and/or lime to heat soil and to enhance the volatilization of contaminants.	• Enhances the volatilization of contaminants. • Effectiveness of in-situ volatilization is reduced by delivery system limitations.	• Subsurface boulders, incomplete VOC emission controls and the inability to add dry reagent create implementability problems.	• Capital: \$100 to \$250 per cubic yard, not including emission controls. • No O&M.	Eliminated auger-type from further consideration. Modified trenching machine would require field demonstrations.
Biological Treatment	Breakdown of organic contaminants in waste by microorganisms; in-situ bioreclamation or ex-situ slurry reactor were considered.	• These processes are not effective for the concentrations of site-related compounds.	• Biological systems are available, and can be implemented if proven effective from treatability testing.	Not determined.	Eliminated from further consideration because biotreatment is not effective for the concentrations of site-related compounds found.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
Soil Flushing (with Chemical Solvents)	In-Situ injection or percolation of a chemical flushing solution into the area of contaminated soil, followed by collection of the treatment fluid and mobilized contaminants in downgradient recovery wells.	• Could increase DNAPL mobility and migration. • Effectiveness limited by soil heterogeneity.	• May not be able to control and monitor the effects of the action. • The collected solution would require treatment/disposal.	• Capital: \$1 to \$3 million. • O&M: \$500,000 to \$2 million per year.	Eliminated from further consideration because of lack of added benefits over more proven/cost-effective technologies.
Chemical Oxidation	A type of soil flushing utilizing oxidizing agents such as hydrogen peroxide and permanganate.	• Effectiveness is limited by soil heterogeneity. • May produce undesirable by-products.	• May not be able to control and monitor the effects of the action. • The collected solution would require treatment/disposal.	• Not determined	Eliminated from further consideration because of lack of added benefits over more proven/cost-effective technologies.
Stabilization	Additives are mixed with the contaminated soil to reduce contaminant mobility via a reduction in permeability, and/or physical or chemical binding.	• Not applicable for high concentrations of organic contaminants. • Does not destroy contaminants.	• Subsurface conditions (e.g., boulders) would inhibit complete mixing.	• Capital: \$200 to \$400 per cubic yard. • No O&M.	Eliminated from further consideration due to limited effectiveness and implementability problems.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION **Technology Type**	**Description**	**Effectiveness**	**Implementability**	**Cost**	**Screening Result**
Soil Heating/Vitrification	A group of technologies which involve the direct in-situ heating of soils to enhance volatilization of contaminants for collection at the ground surface. Vitrification also includes the melting of soil to immobilize contaminants.	• Unfavorable site conditions (DNAPL, wet soils, etc.) would limit effectiveness of soil heating. • Effectiveness of in-situ vitrification has recently come under question due to entrapment of volatilized gases during soil melting which can later become mobile.	• Units are still in developmental stages and availability is severely limited.	• Capital: $500 to $1,000 per cubic yard.	Eliminated from further consideration due to questionable effectiveness, implementability problems and relatively high cost.
EX-SITU TREATMENT:					
Ambient Temperature Volatilization	Ex-situ processes of aggressive aeration (e.g., screening, tilling, discing).	• Does not effectively remove VOCs to low concentrations.	• Simple to implement. • Requires significant materials handling and emission controls.	• Capital: $50 to $100 per cubic yard, not including lime addition or emission controls. • No O&M.	Eliminated from further consideration due to limited effectiveness and implementability concerns.
Ex-situ Volatilization	Enhanced volatilization by low temperature (<200°F) soil heating and/or mixing to enhance the volatilization of contaminants.	• Does not effectively remove VOCs to low concentrations.	• Pilot-scale testing would be required; technology not proven.	• Not determined.	Eliminated from further consideration due to limited effectiveness.

Table 2-2 Summary of Technology Screening (Cont'd)

RESPONSE ACTION Technology Type	Description	Effectiveness	Implementability	Cost	Screening Result
Solvent Extraction/Soil Washing	Extraction of contaminants from soil through organic solvents/surfactants.	• Less effective than competitive technologies. • Residuals required subsequent treatment/disposal.	• Pilot-scale testing would be required. • Limited availability of full-scale equipment.	• Not determined.	Eliminated from further consideration because of lack of added benefits over more proven/cost-effective technologies.
Low Temperature Thermal Desorption (LTTD)	This process volatilizes VOCs from solids at elevated temperatures typically in the range of 200 to 1,200° F. A mobile unit would be set up on site.	• Can achieve relatively low cleanup levels for VOCs. • High VOC concentrations and wet soils can limit effectiveness somewhat.	• This technology is readily available. • Air emission controls are required.	• Capital: \$200 to \$375 per cubic yard, not including soil backfilling or disposal. • No O&M.	Retained for further consideration because of its effectiveness and cost-competitiveness.
Incineration	High temperature oxidization under controlled conditions to degrade waste materials.	• Proven effectiveness for the destruction of organic contaminants.	• Public opposition to an on-site incinerator could be substantial. • Limited on-site area for siting. • Trial burn and emission controls would be required. • Off-site incineration would require construction of rail spur and loading dock.	• Capital: \$500 to \$1,000 per cubic yard, not including backfilling or disposal of treated soils for on-site incineration. \$800 to \$1,350 per cubic yard for off-site incineration.	On-site incineration is eliminated from further consideration at this time because of implementation concerns. Off-site incineration is retained for further consideration.

2.5 DEVELOPMENT OF FEASIBLE ALTERNATIVES

Based on a significant evaluation of remedial technologies in the previous section, a focused list of applicable technologies have been retained for the development of remedial alternatives in this section.

2.5.1 Basis for Alternative Development

2.5.1.1 General

To be consistent with the current understanding of site conditions and the remedial action objectives developed in Section 2.1, the remedial alternatives are developed in consideration of certain technical and engineering issues discussed in the sections below.

2.5.1.2 Surface Water Infiltration

The reduction of surface water infiltration is not a requirement for the soil cover or the multilayer cap components of any remedial alternative since a significant volume of DNAPL and contaminated soil and bedrock presently exist below the ground water table, and a long-term ground water recovery and treatment system is currently operating to contain further migration of affected ground water from the site. No further degradation of ground water quality is expected to result from the relatively small VOC mass in the lagoon area soils as compared to the VOC mass estimated to be present in saturated bedrock (see Attachment A of the 14 July 1994 Exposure Assessment Memorandum).

2.5.1.3 Institutional Controls

All of the alternatives include perimeter security fencing and associated security measures to physically restrict unauthorized access and to reduce the potential for exposure to the lagoon area soils. Long-term deed restrictions and/or easement agreements are also included as part of each alternative to provide for long-term control of future property uses as required for implementation, operation, and maintenance of remedial measures for the Tyson's Site, as well as to restrict site uses with potential for increased exposure risks.

2.5.1.4 *Direct Contact Exposures*

The SVE system has preferentially removed the more volatile and more mobile constituents, and has resulted in the upper few feet of soil being relatively clean. While direct contact exposures have been reduced, the prevention of direct contact exposures is considered essential for the intended future use and for potential unauthorized trespassers on the lagoon area.

To eliminate potential direct contact exposures, each of the alternatives includes a physical barrier such as a soil cover or cap to be placed over either existing contaminated or backfilled lagoon area soils. The areal extent of such physical barriers will be as necessary to cover the lagoon area soils, and provide acceptable direct contact protection.

2.5.1.5 *VOC Emissions*

Because of the relatively high VOC concentrations and DNAPLs present in the lagoon area soils and particularly in the underlying bedrock, VOC emissions from the lagoon area present potential exposure risks both during and following implementation of each remedial alternative. To address this concern, the remedial alternatives include a range of potentially applicable measures for controlling VOC emissions from the lagoon area soils.

Volatilization of VOCs present within the lagoon area soils and underlying DNAPL-impacted bedrock releases VOC vapors into the air spaces between particles of the lagoon area soils. As long as DNAPL contamination of the underlying bedrock persists, VOC vapors will migrate upward over time from areas of high soil-pore-air concentrations to areas of lower soil-pore-air concentrations. This upward migration of VOC vapors towards the ground surface ultimately results in long-term VOC emissions to the atmosphere. If the lagoon area soils are excavated for subsequent treatment and/or disposal, and clean backfill or remediated soils are replaced, the upward migration and emission of VOC vapors, although reduced, will continue because of the underlying DNAPL source areas. In addition, short-term VOC emissions would result from the displacement of gases from the soil pores during excavation and handling, as well as from increased volatilization caused by the exposure of more highly contaminated soils. As discussed below, the remedial alternatives utilize various measures as appropriate to address the control of long- and short-term VOC emissions.

Long-term (i.e., residual or after implementation) VOC emissions are addressed by technologies such as a soil cover, a clay cap and a wet soil barrier. The ability of a soil cover to control residual VOC emissions is limited, although VOC emissions are reduced by lowering the diffusion concentration gradient (i.e., by increasing the thickness of soil through which VOC vapors must migrate). A clay cap can restrict upward VOC vapor migration and resulting VOC emissions more effectively than a soil cover. The greater effectiveness of the clay layer is a result of its ability to maintain a high water content during and following placement so that the air-filled porosity of the clay layer is minimized. In a similar manner, a wet or saturated soil barrier will restrict the migration of organic constituents to aqueous diffusion which is several orders of magnitude lower than vapor-phase migration for the compounds of concern. These approaches provide a varying degree of protection against long-term VOC emissions, and are incorporated into the remedial alternatives as appropriate to achieve the desired level of protectiveness.

As discussed above, increased VOC emissions created during soil excavation, processing and handling were identified as an important consideration for the alternatives that include excavation of contaminated soils. This concern prompted an evaluation of potential VOC emissions and potential methods for controlling such emissions if warranted. A more detailed evaluation of VOC emissions during soil excavation is presented in Appendix C (Soil Removal Analysis).

2.5.1.6 Recontamination

Aqueous-phase contamination of any treated or clean soils within the saturated zone will result from the intrusion of contaminated ground water into this zone. As discussed in Section 2.5.1.7 (below), it is not practical to prevent the intrusion of ground water into the saturated zone soils, and furthermore, such soils are considered as part of the ground water regime.

Vapor-phase recontamination of treated or clean soils above the saturated zone will result from the upward migration of VOC vapors from the DNAPL-impacted bedrock and saturated soils underlying the lagoon area surface soils. The rate of this upward migration is controlled by soil-water VOC partitioning, diffusion, and the depth of clean soil placed above the source of the VOC vapors.

Soil recontamination and its impact were incorporated into the development and evaluation of the remedial alternatives. Soil recontamination has been considered in establishing the expected residual

VOC emissions and associated risks, projecting probable soil concentrations at various depths in the lagoons, and in determining the volume of soils to be excavated and the degree of treatment appropriate for the excavated soils.

A more detailed evaluation of both aqueous-phase and vapor-phase recontamination processes is presented in Appendix D (Recontamination Evaluation).

2.5.1.7 *Prevention of Soil Recontamination*

Parallel to evaluating the impact of recontamination, as discussed above, the ability to protect treated or clean backfill soils from recontamination was also evaluated. This evaluation focused on the practicality of "bedrock sealing" technologies to prevent aqueous-phase recontamination of clean soils placed within the saturated zone, and the practicality of "soil sealing" technologies to prevent vapor-phase recontamination of backfill soils located above the saturated zone.

Based on the detailed evaluation of bedrock sealing options, it was concluded that grouting, flexible membrane liners and clay barriers will not protect clean soils placed within the saturated zone. The intrusion of contaminated ground water through any such barrier could result in recontamination of the clean soils in as short as 20 years. The inability to inspect and maintain the barrier system is also a major concern.

The evaluation of soil sealing technologies concluded that soils placed above the saturated zone could be protected from vapor-phase recontamination in the short-term by a clay barrier constructed above the top of the saturated zone. However, long-term inspection and maintenance of the barrier would be difficult, and there would be additional short-term exposure risks during installation of a clay barrier in the subsurface (e.g., large working areas required). Weighing the benefits of protecting the relatively small volume of clean backfill soils that would be placed in the unsaturated zone against the implementation and maintenance concerns, the more appropriate solution is to locate the clay barrier at the surface to reduce VOC emissions to the atmosphere.

A more detailed discussion of this evaluation is presented in Appendix E (Bedrock and Soil Sealing).

2.5.1.8 *Soil Volume Considered for Excavation*

Based on the evaluation and sensitivity analysis presented in Appendix C (Soil Removal Analysis), the soil removal and treatment alternatives for the lagoon area soils consider removal of only unsaturated zone soils with average total VOC concentrations greater than 1,000 mg/kg. Removal or treatment of soils within the saturated zone is not included because such soils are part of the ground water regime, would be recontaminated from the intrusion of contaminated ground water, and will be addressed by the ground water remediation program. Further, the implementation risks associated with excavating soils located at depth outweigh any long-term risk benefits. The volume of unsaturated soils with average total VOC concentrations greater than 1,000 mg/kg was determined to be the most appropriate excavation volume because of the significant VOC mass estimated to be located within these areas and the associated potential reduction of VOC emissions achieved by their removal.

Based on the Terra Vac VOC isoconcentration map (presented in Appendix A), and as presented in Table C-1 of Appendix C, nearly 99% of the VOC mass in the unsaturated zone is estimated to be present within the area defined as having average total VOC concentrations greater than 1,000 mg/kg. The volume of unsaturated soils containing average total VOC concentrations greater than 1,000 mg/kg has been estimated as approximately 13,070 cubic yards (or 19,600 tons), based on the estimated extent of excavation shown on Figure 2-2. This volume includes approximately 2,450 cubic yards of adjacent soils with lower VOC concentrations that would have to be removed to facilitate removal of the soils with VOC concentrations greater than 1,000 mg/kg.

2.5.2 *List of Alternatives*

Based on an evaluation of the retained remedial technologies and consideration of the bases discussed above, the following five (5) remedial alternatives have been developed for the lagoon area soils:

<u>Containment:</u>

- Alternative 1 - Soil Cover;
- Alternative 2 - Capping;
- Alternative 3 - Wet Soil Cover;

<u>Excavation:</u>

- Alternative 4 - LTTD; and:
- Alternative 5 - Off-Site Incineration/Disposal.

Each remedial alternative consists of a core technology and various support technologies. Table 2-3 presents the assembly of remedial alternatives and their component technologies. A detailed evaluation and comparison of remedial alternatives is presented in Section 3.

Figure 2-2
Approximate Extent of Potential Soil Excavation
Tyson's Site
Focused Feasibility Study

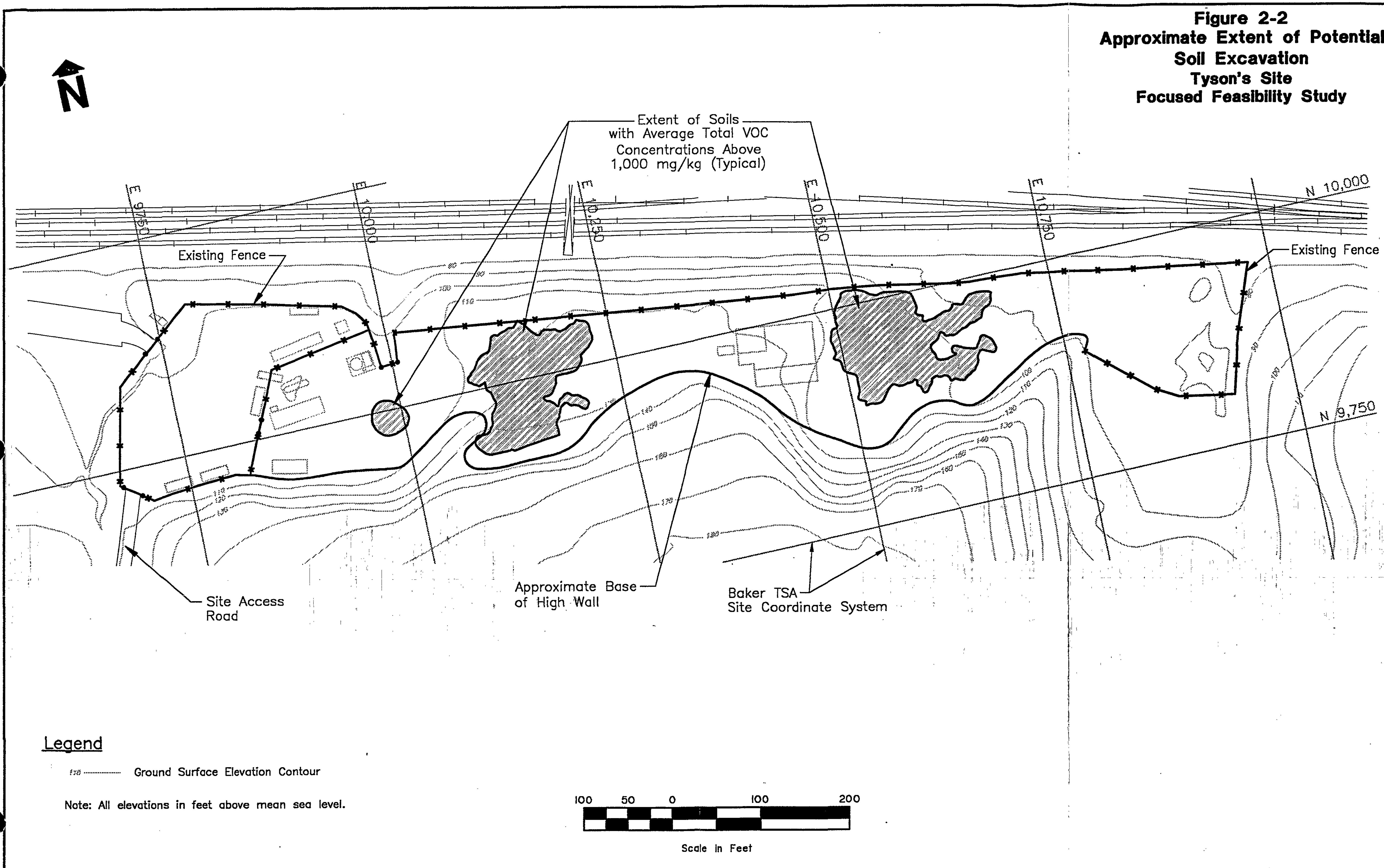

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Table 2-3 *Assembly of Remedial Alternatives*

	REMEDIAL ALTERNATIVES				
Technology	1 Soil Cover	2 Capping	3 Wet Soil Cover	4 *LTTD	5 Off-Site Incineration/Disposal
Fencing	X	X	X	X	X
Deed Restrictions	X	X	X	X	X
Property Control	X	X	X	X	X
Soil Cover	X	X	X	X	X
Clay Cap		X			
Wet Soil Cover			X		
Excavation				X	X
Off-Site Landfill					X
Low-Temp. Thermal Desorption				X	
Off-Site Incineration					X

*Off-site disposal of residuals is required

3.0 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

This section presents a detailed evaluation and comparison of the five alternatives developed in Section 2. In this section, the CERCLA evaluation criteria are reviewed; each alternative is described in detail and an evaluation is provided according to the CERCLA criteria; and a comparison of the remedial alternatives is presented.

3.1 EVALUATION CRITERIA

As required by CERCLA, an evaluation of each alternative has been conducted according to the following nine specific evaluation criteria:

- overall protection of human health and the environment;
- compliance with potential ARARs;
- long-term effectiveness and permanence;
- reduction of toxicity, mobility, or volume;
- short-term effectiveness;
- implementability;
- cost;
- state acceptance; and
- community acceptance.

3.1.1 Overall Protection of Human Health and the Environment

Protectiveness of human health and the environment is based on an evaluation of each alternative's ability to meet the remedial action objectives. This evaluation includes an estimate of risks to human health both during (i.e., short-term risks) and following implementation (i.e., long-term risks) of each alternative. A quantitative determination of total carcinogenic risk based on reasonable maximum exposure (RME) is used for the evaluation and comparison of alternatives. Noncarcinogenic risks are not a concern for any of the remedial alternatives (i.e., the hazard index is less than 1.0 for all cases), and therefore the noncarcinogenic hazard index is not explicitly discussed in the evaluation of alternatives. The detailed Risk Assessment is presented in Appendix F.

3.1.2 *Compliance with Potential ARARs*

Each alternative is evaluated to determine how it complies with potential Federal and State ARARs.

3.1.3 *Long-term Effectiveness and Permanence*

This criterion requires an evaluation of the long-term risk remaining at the site after implementation of the remedy. Issues addressed for each alternative include the magnitude of long-term risks, the suitability of controls used to manage the existing or treated soils, and the long-term reliability of the management controls (i.e., deed restrictions and/or easements).

3.1.4 *Reduction of Toxicity, Mobility or Volume*

This criterion addresses the CERCLA preference for remedial alternatives that permanently and significantly reduce the mobility, toxicity, or volume of the hazardous substances through treatment. Each alternative is evaluated based on the degree to which it destroys or treats hazardous materials; the expected reduction in toxicity, mobility or volume; the extent to which the treatment is irreversible; and the types and quantities of residuals that will remain after treatment.

It is estimated that almost 200,000 pounds of VOCs, or approximately 50% of the contaminant mass originally present in the lagoon area soils, has already been removed by operation of the SVE system. In addition, SVE operation has preferentially removed the more volatile and more mobile constituents from the lagoon area soils. The limited mass removal achieved by SVE over the last 18 months of operation confirms the low mobility of the remaining contaminants. Thus, it can be argued that the CERCLA preference for treatment has been satisfied.

3.1.5 *Short-term Effectiveness*

The evaluation of short-term effectiveness is based on the protectiveness of human health achieved during the construction and implementation phase of the remedial action. Key factors considered in this evaluation include risk to local residents, risk to site workers and the community, and the time required to complete the on-site construction work.

3.1.6 *Implementability*

The implementability of each alternative is evaluated based on its technical and administrative feasibility, and the availability of services and materials. Technical feasibility takes into consideration the difficulties that may be encountered during construction and operation, the reliability of the technologies that make up the alternative, and the ability to monitor the effectiveness of a remedy. Administrative feasibility factors include coordination with other offices and agencies, such as obtaining permits or approvals for various on-site and off-site activities. Availability of services and materials includes the necessary equipment, specialists, materials, and off-site treatment, storage, and disposal services and capacities. The overall implementation schedule estimated for each alternative is also considered.

3.1.7 *Cost*

Evaluation of the cost of each alternative includes the estimation of capital costs, operation and maintenance (O&M) costs, and the net present worth. To demonstrate the variability of the estimated costs, a range of costs has been presented to show a reasonable low-end and reasonable high-end cost for each alternative. Both low and high estimates include a 20 percent contingency. Capital costs consist of the direct costs for items such as labor, materials, equipment, land, and services, plus the indirect costs for engineering, management, permits, startup, and contingencies. O&M costs include operating labor, maintenance, auxiliary materials and energy, monitoring, inspection, and periodic site reviews. The present worth cost provides a means of comparing the costs of different alternatives.

3.1.8 *State Acceptance*

Input from the State of Pennsylvania Department of Environmental Resources (PADER) will be incorporated by EPA during review and approval of this FFS. Therefore, this FFS does not address state acceptance.

3.1.9 *Community Acceptance*

Evaluation of the community responses or concerns about the alternatives will be made by EPA based on public comments received through public meetings and written comments on EPA's proposed plan. Therefore, this FFS does not address community acceptance.

3.2 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

3.2.1 Alternative 1 - Soil Cover

3.2.1.1 Description

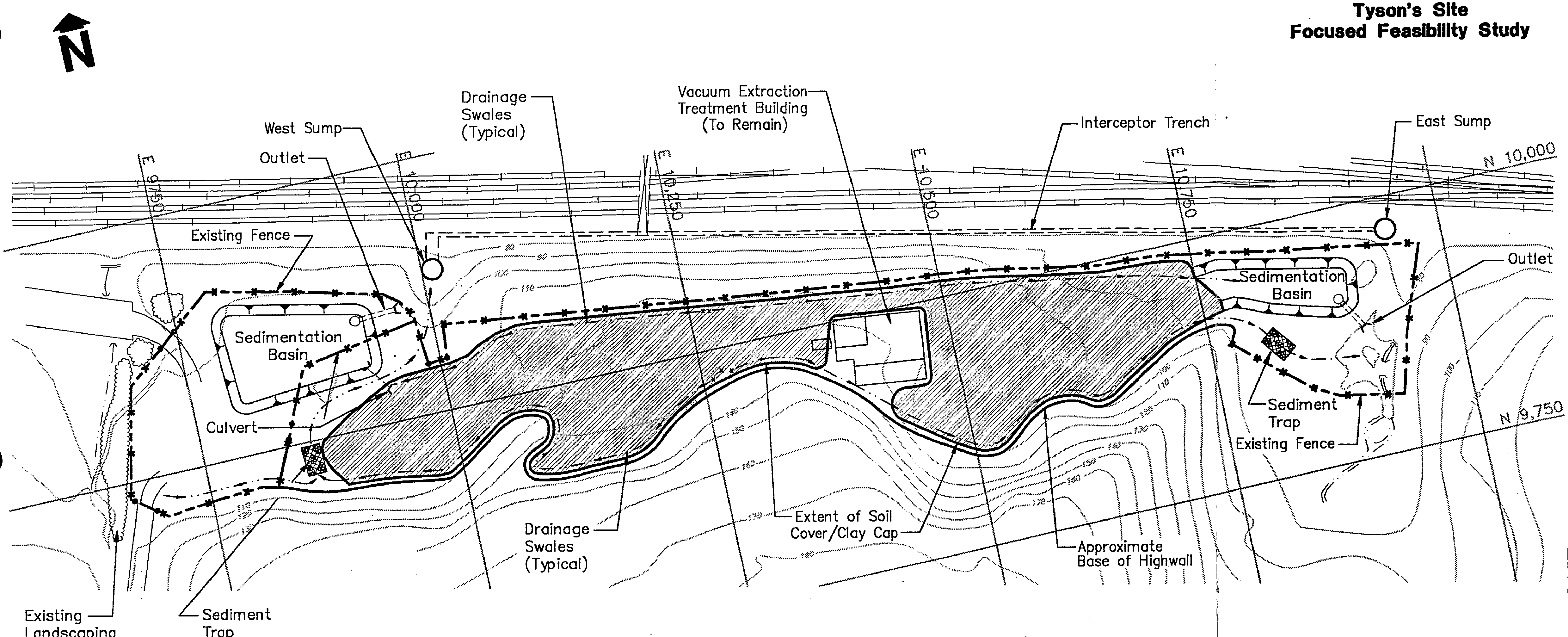
This alternative generally consists of covering the lagoon area soils with an 18-inch to 24-inch-thick vegetated soil cover. Specific components of this alternative include the following:

- Construction support zones and facilities.
- Remove the above-ground and near-surface portions of the existing SVE wells and pipes that would interfere with grading or soil cover activities, and abandon the remaining subsurface wells and pipes in an appropriate manner.
- Establish erosion and sedimentation controls (e.g., silt fences, sediment traps, and sedimentation basins) as required prior to earthmoving activities.
- Conduct limited clearing, grading and filling of the site as required for the cover subgrade and drainage features.
- Place 18 to 24 inches of clean imported borrow soils over the lagoon area soils. The cover will include the following components (from the top down):
  - 6-inch vegetated topsoil layer; and
  - 12- to 18-inch cover layer of imported general fill soils.
- Implement property deed restrictions and/or easement agreements, and upgrade security measures if necessary.

Based on previous characterization activities for the lagoon area soils, the total area to be covered is approximately 2.5 acres. The extent and general configuration of the soil cover is presented on Figure 3-1.

Surface water control measures for the cover will include a sloped surface leading to perimeter drainage swales and sediment basins as necessary. A ditch along the southern edge of the area will be included to intercept run-off of surface water from the southern high-wall area. A gabion, concrete block or alternate small retaining wall may be used along portions of the northern edge of the area to join the cover with the steep northern slopes. An irrigation system will be included as necessary to maintain the vegetative cover.

Figure 3-1
General Soil Cover/Cap Layout
Tyson's Site
Focused Feasibility Study



Note:

THE EXISTING FENCE WILL BE UPGRADED AND EXTENDED AS REQUIRED.

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Institutional controls include upgrading and extending as necessary the perimeter security fence to further restrict unauthorized site access. Periodic site inspections will be conducted to help detect changes in site conditions which may require actions to maintain the integrity of the security fence and soil cover. Deed restrictions and easement agreements will provide for long-term control of the site as required to minimize potential future risks and to provide for the maintenance and implementation of required remedial activities.

3.2.1.2 *Evaluation*

Overall Protection of Human Health and the Environment

The objective of this remedy is to provide containment of the contaminated soils in order to achieve adequate protection of human health. By securing the contaminated soil under an engineered cover, this alternative will reduce VOC emissions, eliminate potential direct contact and ingestion exposures to contaminated lagoon area soils, and minimize migration of contaminants into the surface environment from wind and water erosion.

Although the soil cover does not completely control VOC emissions, it does prevent potential direct contact and ingestion exposure risks and erosion of contaminated soil. As a result, the estimated total carcinogenic risk associated with this alternative is less than $8x10^{-5}$ for all receptors. These potential risks are within EPA's target risk range of $1x10^{-4}$ to $1x10^{-6}$. Thus, this alternative meets the remedial action objectives.

Compliance with Potential ARARs

This alternative is expected to comply with all potential ARARs. There are no chemical- or location-specific ARARs of potential concern, and this alternative can be designed and implemented to meet all action-specific ARARs (e.g., appropriate erosion and sedimentation controls will be utilized).

Long-term Effectiveness and Permanence

Because the soil cover is constructed of general fill soils, rather than low-permeability materials, its ability to control residual VOC emissions from the lagoon area soils is limited. However, the soil cover will provide some reduction in VOC emissions by increasing the thickness of soil through which VOC vapors must migrate. The long-term carcinogenic risk associated with this alternative is within EPA's target risk range.

The risk reduction achieved by this alternative will remain effective for as long as the integrity of the soil cover is maintained. A routine maintenance program and the effectiveness of the vegetative cover to prevent erosion will ensure the long-term integrity of the soil cover. Although surface water infiltration will slowly and gradually remove a minor amount of contaminants from the lagoon area soils through natural attenuation, contamination is expected to remain in the lagoon area soils for a period of time consistent with the expected duration of ground water remediation. Any contaminants that migrate to ground water will be contained and recovered by the existing ground water recovery and treatment system.

Long-term deed restrictions and/or easements will be implemented to restrict future site uses which could compromise the effectiveness of the soil cover.

Reduction of Toxicity, Mobility or Volume

The soil cover will somewhat restrict the mobility of contaminants by reducing VOC emissions and controlling erosion of contaminated soils, but will not achieve any reduction in toxicity, mobility or volume through treatment. Some reduction in toxicity and volume will occur through natural attenuation.

Short-Term Effectiveness

This alternative requires minimal site disturbance, and can be implemented quickly. Construction of the soil cover can be completed within 3 to 4 months, and the positive effects of implementing this alternative will be realized immediately. Short-term risks associated with this alternative are not significant (i.e., $<1x10^{-6}$), as only minor disturbance and covering of contaminated soils are required, and because the implementation schedule is short.

Implementability

The design, construction and maintenance of this remedy is relatively common, straight forward and readily implementable. Engineering and construction services, materials and equipment are readily available. This remedy does not require any special permits or approvals other than routine construction-related permits. The schedule required for this remedy is about 17 to 18 months, including design, agency review, bidding, and construction. In summary, this remedy can be implemented relatively quickly and easily.

Cost

Table G-1 of Appendix G (Detailed Cost Estimates) presents the estimated cost for the soil cover alternative, based on an assumed 30-year operation and maintenance period. Total estimated costs are:

• Total Capital Cost	$812,000 to $1,073,000
• Present Worth O/M Cost	$715,000
• Total Project Cost	$1,528,000 to $1,788,000

3.2.2 *Alternative 2 - Capping*

3.2.2.1 *Description*

This alternative consists of covering the lagoon area soils with a cap that includes a 2-foot-thick clay layer and a vegetative soil layer to restrict VOC emissions. Specific components of this alternative include the following:

- Construction support zones and facilities.
- Remove the above-ground and near-surface portions of the existing SVE wells and pipes that would interfere with grading or capping activities, and abandon the remaining subsurface wells and pipes in an appropriate manner.
- Establish erosion and sedimentation controls (e.g., silt fences, sediment traps and sedimentation basins) as required prior to earthmoving activities.
- Conduct clearing, grading, filling and compaction of the lagoon soils as required for the cap subgrade and drainage features.
- Construct a clay cap over the lagoon area soils. The cap will include the following components (from the top down):
    - 6-inch vegetated topsoil layer;
    - 12 to 18-inch compacted cover soil layer; and
    - 24-inch compacted clay layer.
- Implement property deed restrictions and/or easement agreements, and upgrade security measures if required.

Based on previous characterization activities for the lagoon area soils, the total area to be covered is approximately 2.5 acres. The extent and general configuration of the clay cap is presented on Figure 3-1.

To maximize the reduction of VOC vapor emissions, the clay layer will be compacted to a relatively high density and high moisture content so as to minimize the total air porosity. An irrigation system will be included as necessary to maintain the vegetative cover and high moisture content within the clay layer.

Surface water control measures for the cap will include a sloped surface leading to perimeter drainage swales and sediment basins as necessary. A drainage swale along the southern edge of the area will be included to intercept run-off of surface water from the southern high-wall area. A gabion, concrete block or alternate small retaining wall may be used along portions of the northern edge of the area to join the cap with the steep northern slopes.

Institutional controls include upgrading and extending as necessary the perimeter security fence to further restrict unauthorized site access. This alternative also includes periodic site inspections to help detect changes in site conditions which may require actions to maintain the integrity of the site fence and cap. Deed restrictions and easement agreements will provide for long-term control of the site as required to minimize potential future risks and to provide for the maintenance and implementation of required remedial activities.

If it is determined that the residual risks associated with this alternative are not acceptable, the clay cap can be constructed with a granular venting layer beneath the clay layer to provide for the active venting of VOCs beneath the cap. The venting layer will be constructed of 8 to 12 inches of granular material embedded with perforated vent pipes. If required based on monitoring, the vent pipes will be connected to a vacuum pump. This active venting will remove VOC-laden air from the venting layer, thus minimizing the migration of VOC emissions through the cap system. The air stream will pass through a vapor-phase carbon adsorption system prior to being exhausted to the atmosphere.

3.2.2.2 *Evaluation*

<u>Overall Protection of Human Health and the Environment</u>

The objective of this remedy is to provide containment of the contaminated soils so as to adequately protect human health. By securing the contaminated soil under an engineered cap, this alternative will minimize VOC emissions from the lagoon area soils, eliminate potential direct contact and ingestion exposures to contaminated lagoon area soils, and eliminate migration of contaminants into the surface environment from wind and water erosion.

The estimated total carcinogenic risks for this alternative are within or below EPA's target risk range. This alternative also includes a provision for active gas venting to achieve total risks below EPA's target risk range (i.e., $<1\times10^{-6}$) for all exposure scenarios. Thus, this alternative meets the remedial action objectives.

Compliance with Potential ARARs

This alternative is expected to comply with all potential ARARs identified. There are no chemical- or location-specific ARARs of potential concern, and this alternative can be designed and implemented to meet all action-specific ARARs (e.g., appropriate erosion and sedimentation controls will be utilized).

Long-term Effectiveness and Permanence

By maintaining a high moisture content and minimizing the air-filled porosity of the clay layer during and following placement, VOC emissions through the clay layer will be minimized. The long-term carcinogenic risks presented by this alternative are within or below EPA's target risk range.

The risk reduction achieved by this alternative will remain effective for as long as the integrity of the cap is maintained. To maintain its integrity, this alternative requires long-term operation and maintenance such as mowing, re-seeding, repair of erosion, and fence repair. The routine maintenance program and the effectiveness of the vegetative cover to prevent erosion will ensure the long-term integrity of the clay cap. Because of the relatively high field capacity of clays, the clay layer will retain its high moisture content and low air filled porosity. An irrigation system may be included, if necessary, to maintain the vegetative cover and high moisture content in the clay layer. If active venting is conducted, this alternative will also require long-term operation and maintenance for items such as blower operation, treatment of VOC vapors and replacement of vapor-phase carbon. The cover soils above the clay layer will protect the clay layer from damage and desiccation.

Long-term deed restrictions and/or easement agreements will be implemented to restrict future site uses which could compromise the effectiveness of the alternative.

Reduction of Toxicity, Mobility or Volume

The cap will provide some reduction in the mobility of contaminants by reducing VOC emissions and controlling erosion of contaminated soils, but will provide no further reduction in toxicity and volume beyond that achieved by SVE. Active venting will reduce potential contamination of the clay.

Short-term Effectiveness

This alternative requires minimal site disturbance, and can be implemented in a relatively short time. Construction of the cap can be completed within 4 to 5 months, and the positive effects of implementing this alternative will be realized immediately. Short-term risks associated with this alternative are not significant (i.e., $<1x10^{-6}$), as only minor regrading and covering of contaminated soils are required, and because the implementation time is short.

Implementability

The design, construction and maintenance of this remedy is relatively common and easy to implement. Engineering and construction services, materials, and equipment are readily available. This remedy does not require any special permits or approvals other than routine construction-related permits. The schedule required for this remedy is about 18 to 20 months, including design, agency review, bidding, and construction. In summary, this remedy can be implemented relatively quickly and easily.

Cost

Table G-2 (Appendix G) presents the estimated cost for the capping alternative, based on an assumed 30-year operation and maintenance period, and assuming that active gas venting is conducted. Total estimated costs are:

- Total Capital Cost $1,218,000 to $1,614,000
- Present Worth O/M Cost $1,132,000
- Total Project Cost $2,350,000 to $2,746,000

3.2.3 *Alternative 3 - Wet Soil Cover*

3.2.3.1 *Description*

The wet soil cover alternative consists of a nearly saturated compacted soil layer overlain by an infiltration blanket and a vegetated soil cover (Figures 3-2 and 3-3). Water (municipal water or treated ground water) is introduced as needed ~~to~~ to maintain the nearly saturated compacted soil layer. It is anticipated that a low rate of water usage is required (5 gpm or less) as described in Appendix H. Water will percolate through the wet soil layer into the lower layers of the lagoon area soils to virtually eliminate upward migration of VOC vapors. The added water will combine with the natural ground water beneath the lagoon area.

Addition of water during the winter months may be unnecessary. During the colder months, temperatures may require shutting off surface infiltration water. If this occurs, the compacted soil layer will likely continue to be an effective VOC vapor barrier since it will maintain some saturation as dictated by its field capacity.

The shallow ground water flows to the existing seep collection system along the northern area of the lagoon area adjacent to the Conrail rail yard. Deeper ground water flows to the existing ground water recovery and treatment system. Continuing operation of the french drain, sump pumps and ground water well pumps will collect the added water and ground water for treatment. The site layout for this alternative is very similar to that shown on Figure 3-1 for the Soil Cover alternative. The components of the Wet Soil Cover alternative include the following:

- Construction support zones and facilities.
- Removal of the above-ground and near-surface portions of the existing SVE wells and pipes that would interfere with construction activities.
- Establishment of erosion and sedimentation controls (e.g., silt fences, sediment traps and sedimentation basins) as required prior to earth moving activities, and abandon the remaining subsurface wells in an appropriate manner. Addition of a small amount of clay may be required if terracing is used.
- Limited clearing, grading, filling, and compaction of the site as required for adequate site drainage.

Figure 3-2
Typical Cross-Section of Wet Soil Cover
Tyson's Site
Focused Feasibility Study

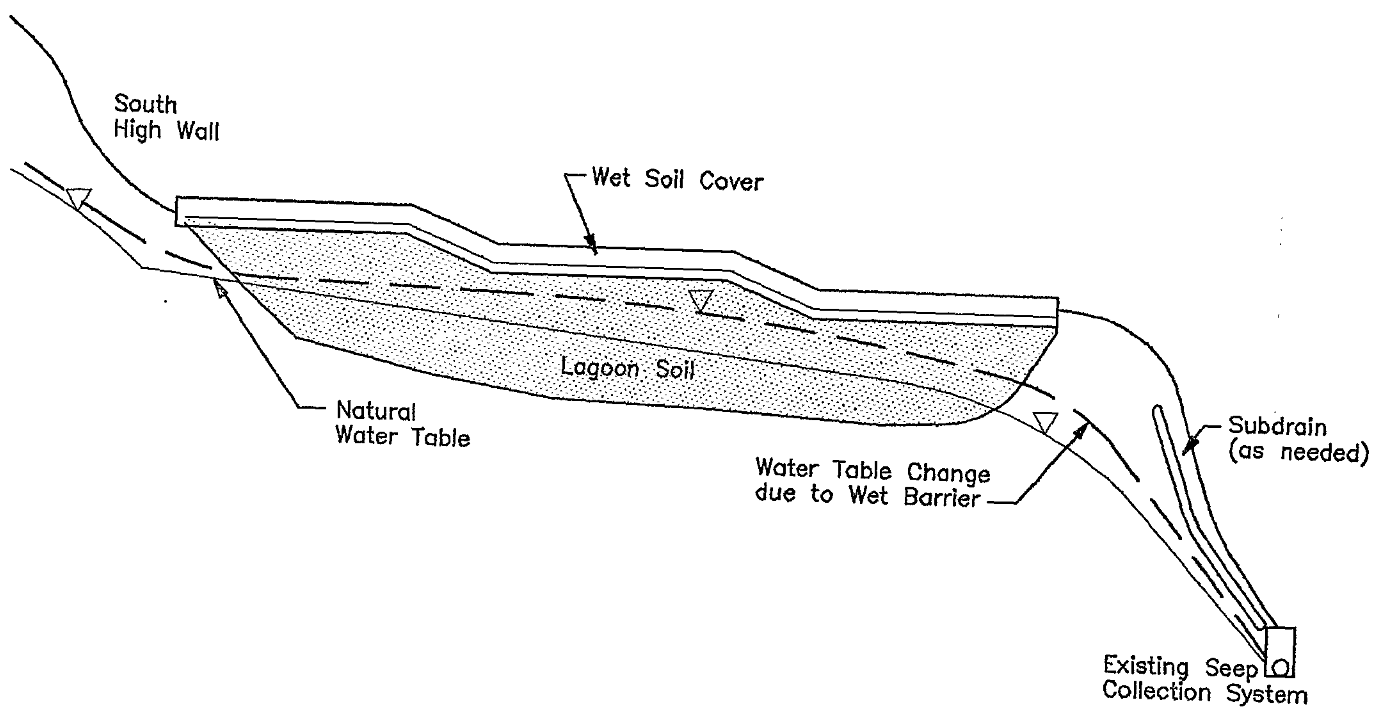
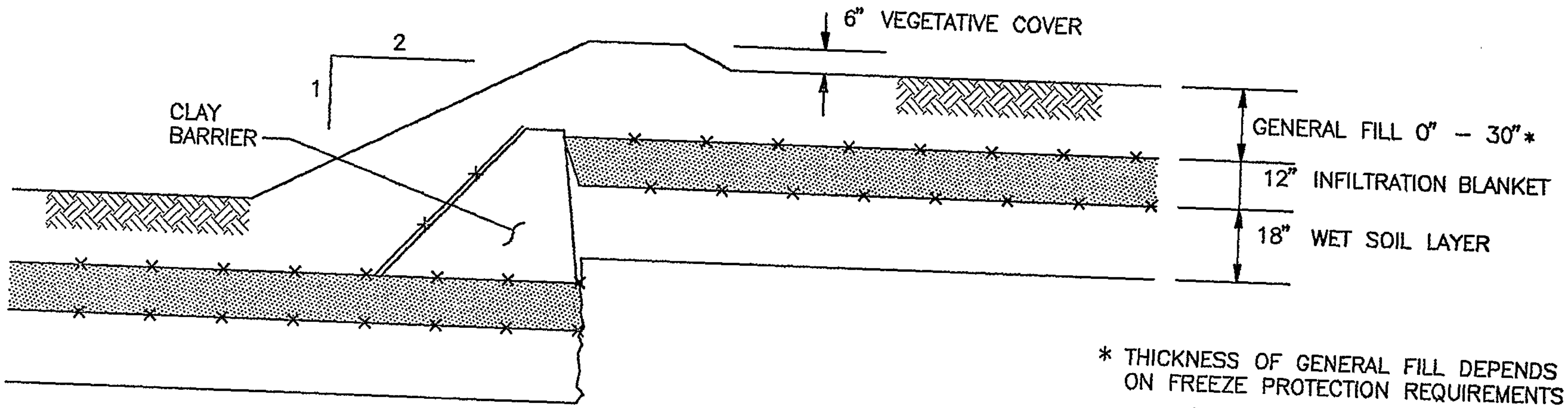


Figure 3-3
Typical Cross-Section of Wet Soil Cover
Tyson's Site
Focused Feasibility Study



- Preparation of a base grade through use of imported borrow material.
- Preparation of the wet soil layer by homogenizing and compacting 18 inches of relatively uniform borrow material.
- Installation of an infiltration blanket (layer of soil or crushed stone), an irrigation system and shallow monitoring piezometers.
- Installation of the water supply system including piping, valves, and controls to distribute water.
- Placing a cover system that includes 0 to 30 inches of imported general fill soils overlain by a 6-inch vegetated topsoil layer (actual depth of general fill dependent on freeze/thaw damage potential).
- If required, upgrading of the existing seep collection system.
- Installation of horizontal subdrains, as needed, along the north high wall.
- Implement property deed restrictions and/or easement agreements, and upgrade security measures if required.

Institutional controls include upgrading and extending as necessary the perimeter security fence to further restrict unauthorized site access. This alternative will also include periodic site inspections to help detect changes in site conditions which may require additional actions. Deed restrictions and easement agreements will provide for long-term control of the site as required to minimize potential future risks and to provide for the maintenance and implementation of required remedial activities.

To achieve the remedial action objectives without spreading contaminants into currently clean areas, this alternative will meet the following three requirements:

- Creation and operation of a nearly saturated soil layer for effective control of VOC emissions;
- Maintaining the natural hydrogeologic balance to prevent unexpected migration of contaminants associated with infiltration water; and:
- Control of any excess water introduced during precipitation events.

The performance of this alternative in meeting these requirements is presented in Appendix H (Evaluation of Wet Soil Cover).

This alternative requires the addition of water to saturate the compacted soil layer. If infiltration water is introduced directly on the lagoon soil, the heterogeneous nature of the lagoon soil will allow infiltration water to flow through preferential pathways of more permeable zones. The hydraulic conductivity of the infiltration blanket must be high enough to provide a uniform distribution of infiltration water over the wet soil layer. To prevent these potential problems, the wet soil layer and the infiltration blanket will be engineered to meet the following requirements:

- A relatively flat, homogeneous compacted layer to achieve a uniform recharge over the entire area; and:
- A moderately high hydraulic conductivity (e.g., $1x10^{-4}$ to $1x10^{-5}$cm/sec) of the infiltration blanket to allow uniform spreading of infiltration water. The infiltration blanket hydraulic conductivity will be an order of magnitude greater that the compacted soil layer.

3.3.3.2 *Evaluation*

Overall Protection of Human Health and the Environment

This alternative will prevent direct exposures to the contaminated lagoon area soils and will effectively eliminate VOC vapor emissions. The total carcinogenic risk estimated for this alternative is less than $4x10^{-7}$ for all receptors, and is therefore generally not significant (i.e., $<1x10^{-6}$). This alternative is consistent and compatible with the site-wide ground water remedy which collects and treats dissolved VOCs in the bedrock aquifer. In addition to the primary objective of preventing VOC vapor emissions from the surface, this alternative offers the potential for enhanced natural attenuation of contaminants from the lagoon area soils. By preventing upward VOC migration, this alternative will prevent contamination of the soil cover. Thus, this alternative meets the remedial action objectives.

Compliance with ARARs

There are no chemical-specific ARARs for this project, and this alternative will not violate any location-specific ARARs. This alternative can be designed and implemented to meet all action-specific ARARs.

Long-term Effectiveness and Permanence

By maintaining a high moisture content in the compacted soil layer VOC emissions will be virtually eliminated. Thus, long-term carcinogenic risks are insignificant.

The effectiveness of the wet soil cover depends water infiltration, water control monitoring, and site security. This alternative requires long-term operation and maintenance, although such activities may be automated with appropriate monitoring and control devices. Since a significant level of personnel, equipment and other resources will be maintained at the site for site-wide ground water remediation, and because the resources required for the operation of the wet soil cover are minimal, this alternative requires only a small additional support effort from the sufficient pool of resources that will be available at the site. Therefore, this remedy will be effective over the long term.

Long-term deed restrictions and/or easement agreements will be placed on the property deed to restrict future site uses and activities which could compromise the effectiveness of the alternative.

Reduction of Toxicity, Mobility or Volume

This alternative will allow for enhanced natural attenuation of contaminants from the lagoon area soils. The mobility of contaminants will be reduced by the wet soil cover which will restrict soil erosion and virtually eliminate VOC emissions. By preventing upward VOC migration, this alternative will prevent contamination of the soil cover.

Short-term Effectiveness

The Wet Soil Cover alternative can be constructed in about 4 to 5 months. During construction, minor disturbance of the surface soil is expected for site grading and wet soil cover construction. The level of exposure to chemicals and emissions from this disturbance is expected to be low. Short-term risks associated with this alternative are insignificant (i.e., $< 1x10^{-6}$).

Implementability

Construction services required to implement this remedy are available. Water recovery and treatment facilities are already operational at the Tyson's Site. Irrigation systems are widely used in the agricultural and landscaping industry. This alternative is expected to take 18 to 20 months for design, agency review, bidding and construction, although long-term operation and maintenance is also required.

Cost

Table G-3 (Appendix G) presents the estimated cost for this alternative, based on an assumed 30-year operation and maintenance period. The estimated costs assume the use of existing facilities for the treatment of recovered water. Total estimated costs are as follows:

• Total Capital Cost	$1,098,000 to $1,505,000
• Present Worth O/M Cost	$992,000
• Total Project Cost	$2,090,000 to $2,497,000

3.2.4 *Alternative 4 - Low Temperature Thermal Desorption (LTTD)*

3.2.4.1 *Description*

This alternative includes excavation of lagoon area soil, on-site treatment of excavated soil by low temperature thermal desorption (LTTD), backfilling the excavated area with treated soil and installation of a soil cover. Widespread field use and prior bench-scale testing provide a basis for using LTTD as a representative on-site treatment technology. Another on-site treatment technology, the modified trenching machine, was evaluated but not developed into an alternative due to its limited number of full-scale applications. However, pilot studies using the modified trenching machine at other sites suggest that the modified trenching machine could potentially achieve effective VOC mass removal at the site. If on-site treatment is determined to be the most appropriate remedy, pilot testing of the LTTD process will be conducted to provide the necessary evaluation and design data. Prior to or during this time period, pilot testing of the modified trenching machine will be conducted to determine if it is more appropriate from the LTTD process. Specific steps of the LTTD alternative include the following:

- Construction support zone and facilities.
- Remove the existing SVE wells and pipes as required.
- Mobilize and set up an LTTD unit, perform a trial run, and obtain the required operation approvals and permits.
- Install an enclosure next to the LTTD unit for emissions control during feed soil preparation.
- Remove soil from the lagoon area by open excavation and haul to the enclosure for feed preparation. Large boulders will be separated from the soils at the excavation area.

- Prepare feed soil in the enclosure, including additional boulder removal, screening through a 6-inch opening grizzly (oversize materials separator) and crushing in a hammermill crusher.
- Ventilate the enclosure and treat exhaust air using the existing SVE vapor treatment unit or alternate facilities.
- Feed the processed soil to the LTTD feed hopper located inside the enclosure. The processed soil exceeding the LTTD process capacity will be diverted to a stockpile inside the enclosure. Soil from this stockpile will be used during the night shifts because excavation and soil preparation are conducted only during the day shift.
- Process the feed soil using the LTTD unit and treat off-gas through the vapor recovery system.
- Stockpile the treated soil.
- Dispose of process residuals at an off-site location.
- Backfill the excavation area with the treated soil, boulders and cobbles.
- Install a soil cover over the backfilled area and other lagoon areas (as described in Section 3.2.1)
- Implement property deed restrictions and/or easement agreements, and upgrade security measures as necessary.

Excavation and treatment includes those soils with total average VOC concentrations in excess of 1,000 mg/kg (about 13,070 cubic yards or 19,600 wet tons). Site conditions after completion of this alternative will be similar to those shown on Figure 3-1.

A more detailed evaluation of soil excavation and feed preparation is presented in Appendix C. Based on this evaluation, open soil excavation is considered to provide the best balance of risk, on-site worker safety and technical concerns. An enclosure for VOC emission control is recommended for LTTD feed soil preparation.

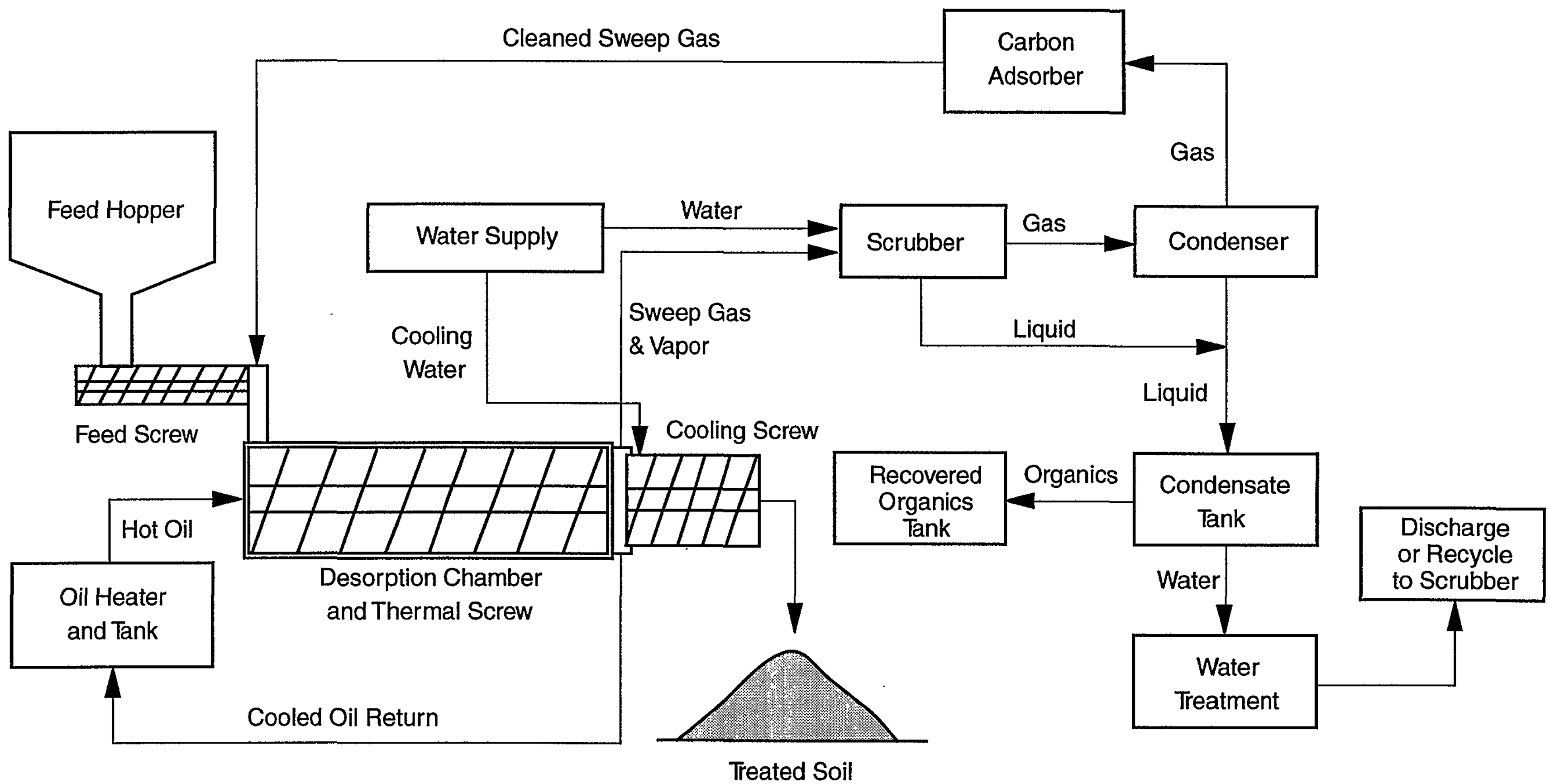
Debris and rocks larger than one-inch size interfere with the efficiency and mechanical operation of the typical, commercial LTTD unit. Therefore, the feed soil will be screened and processed to reduce particle size to acceptable limits. Large boulders which cannot be easily handled by a backhoe will be segregated and stockpiled at the active excavation area. Smaller boulders will be removed from the soil stockpile and cobbles will be screened from the soil within the soil preparation enclosure. Boulders and cobbles larger than 6-inch size will be backfilled at the bottom of the excavation area.

An LTTD unit using indirect heating of the lagoon area soils is used for evaluation of this alternative. However, there are a number of available commercial LTTD processes, and the selection of the most appropriate equipment will be made during remedial design. The indirect heating method minimizes the discharge of off-gas from the treatment process to the atmosphere and avoids the potential of combustion in the desorption chamber. Figure 3-4 shows a schematic of this process which is discussed below:

- Feeding - The feed hopper and the feed screw are used to move the feed soil to the LTTD unit.
- Thermal Desorption - Thermal screws move the soil through the unit and transfer heat to drive off water, volatiles and semivolatiles from the soil. The rotating screw augers are enclosed in a jacketed vessel. Heated oil flows through the hollow augers and jacketed vessel. Diesel fuel or natural gas is used to heat the oil. Cooled oil from the LTTD unit is returned to the oil heater, reheated and reused.
- Vapor Recovery - A non-oxidizing sweep gas is forced through the soil in the desorption chamber to carry organic vapors to the vapor recovery system (VRS). The VRS consists of a scrubber, a condenser, and a carbon adsorption bed. In the scrubber, sprayed water cools the off-gas stream and removes organic vapors. Gas from the scrubber moves to the condenser. Liquids from the scrubber and the condenser are collected in the condensate tank in which organic liquids and water are separated. Liquid organics drain to a storage tank for off-site incineration/disposal. Water is pumped to the existing on-site water treatment facility for treatment. Gas from the condenser flows to the carbon bed in which any remaining organic vapors are removed by contact with carbon. The ability to recycle the clean sweep stream to the desorption chamber minimizes the need to discharge off-gas to the atmosphere. VOCs removed by carbon are desorbed during the carbon regeneration process and subsequently treated by off-site incineration.
- Cooling and Stockpiling - The soil exiting the desorption chamber moves through a cooling screw. The cooling screw cools the heated soil with non-contact cooling water. The soil exiting at the end of the cooling screw is then sprayed with water for dust control and further cooling. The cooled soil is stockpiled for subsequent backfilling in the excavation area. The non-contact cooling water is either discharged or cooled for reuse.

The residence time of soil in the desorption chamber is typically about 60 minutes. With this residence time, the throughput rate of thermal screw

Figure 3-4
LTTD Process Diagram
Tyson's Site
Focused Feasibility Study



type LTTD units to about 5 to 10 tons per hour (TPH). The water content of the feed soil is an important factor controlling the residence time with higher water content requiring longer residence time.

To minimize handling steps, the feed soil preparation enclosure will be located next to the LTTD unit. The LTTD unit requires an approximate area of 80' by 100' including the area required for treated soil handling. The soil preparation enclosure is about 60' x 80'. A 120' x 150' area, as shown in Figure 3-5, is required to lay out both the LTTD unit and the enclosure with access room for support personnel and equipment.

A desirable location for the LTTD unit and enclosure is the existing SVE building area which is centrally located away from the residential area. At this location, exhaust gas from the enclosure can be routed to the existing vapor-phase carbon treatment unit located in the building. However, the space available at this location is very limited. The only other location for the LTTD layout is the current support area at the far west end of the Site. This area is large enough to accommodate the LTTD system and maintain site access and other support functions. However, the proximity to the residential area west of the site could cause objections by the property owners with regard to noise and aesthetics. The general site layout for the LTTD operation at the west end of the Site is shown on Figure 3-6, although the existing SVE building location will also be considered in the future if appropriate. Specific location and equipment arrangement plans to determine optimum LTTD system layout will be performed during detailed design of this alternative.

3.2.4.2 *Alternative Evaluation*

<u>Overall Protection of Human Health and the Environment</u>

Based on screening tests and other case histories, the full-scale system may achieve total VOC concentrations in the range of 10 to 100 ppm. However, long-term VOC migration will recontaminate backfilled soils to levels of 90 to 1,200 mg/kg total VOCs as presented in Appendix D.

This alternative will prevent direct contact exposures and will result in reduced VOC emissions. Immediately after treatment and backfilling, the overall reduction of soil VOC concentrations will be more than 99% for the treated soils. However, the clean backfilled soil will be recontaminated by diffusion of VOC vapors from the underlying DNAPL-affected bedrock through the backfilled soils, resulting in VOC emissions to the atmosphere. Although the levels of this recontamination will be much lower than the current concentrations, the effects of this recontamination will partially offset the VOC mass removal achieved by soil treatment. While recontamination will contribute

Figure 3-5
Enclosure Layout for LTTD Process
Tyson's Site
Focused Feasibility Study

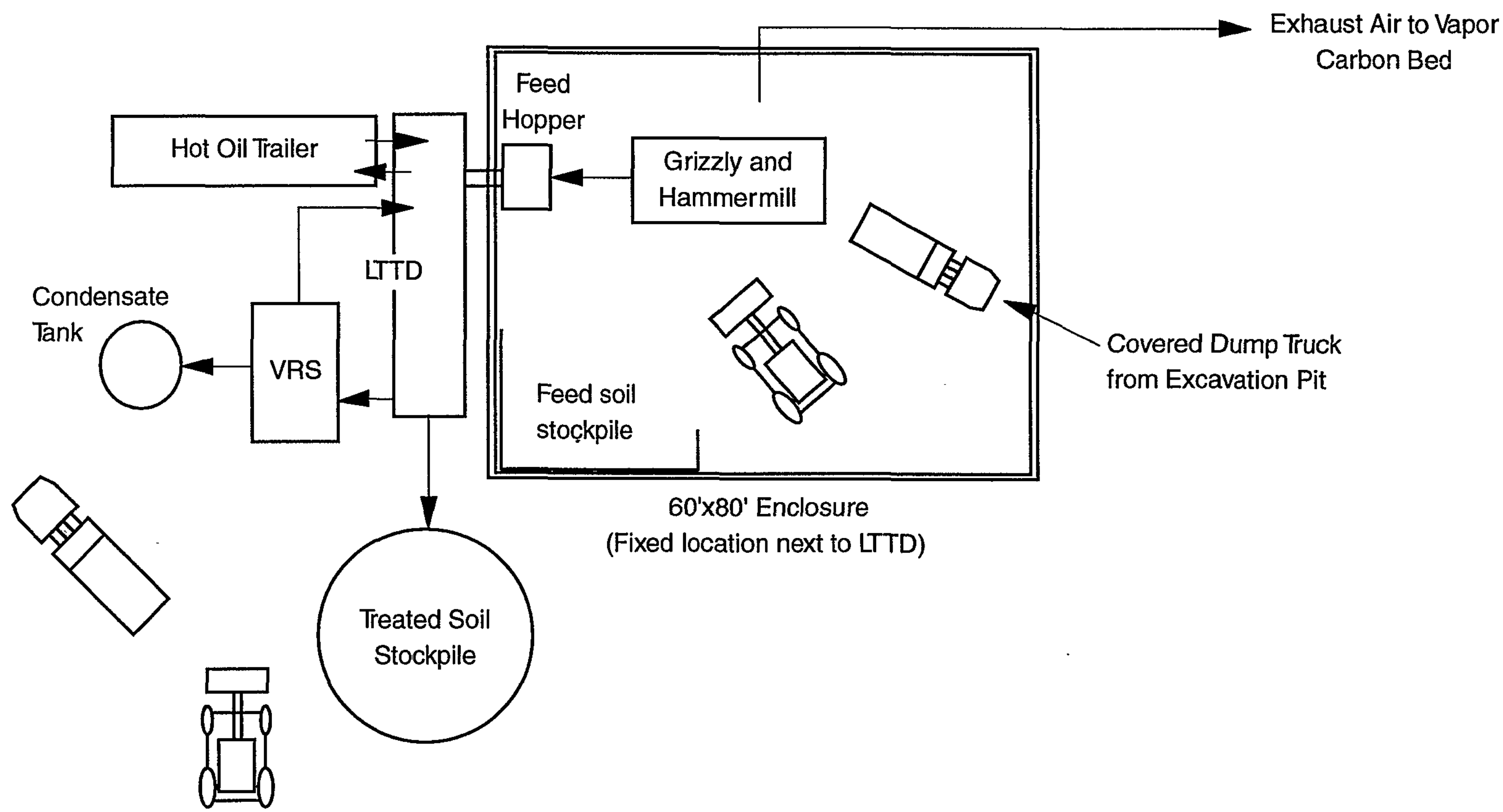
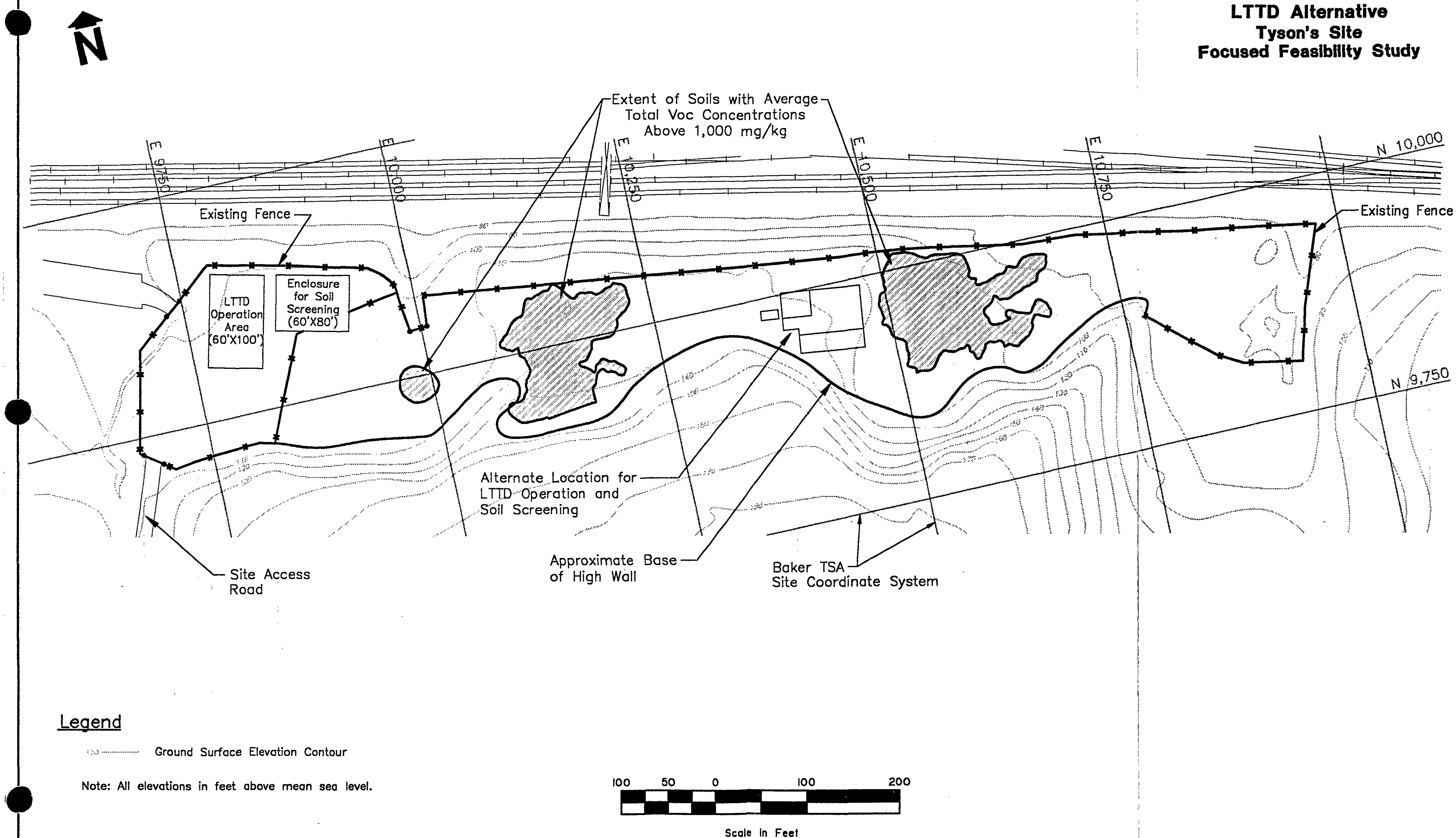


Figure 3-6
Site Layout for
LTTD Alternative
Tyson's Site
Focused Feasibility Study



ERM, INC.

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27222.01.01/10.17.94-tjb/F:\DRAWINGS\TYSON\FO-005.DWG to long-term residual VOC emissions and subsequent risk, the total carcinogenic risks estimated for this alternative are less than $7x10^{-5}$ for all receptors. These potential risks are within EPA's target risk range.

Compliance with ARARs

There are no chemical-specific ARARs for this project, and this alternative will not violate any location-specific ARARs. This alternative is expected to comply with all action-specific ARARs (e.g., air emission controls, erosion and sedimentation controls, etc.). Land disposal restrictions will not apply to the treated soil so long as the lagoon area soils and the LTTD unit are considered to be part of the same corrective action management unit (CAMU).

Long-term Effectiveness and Permanence

The treatment level achieved by this alternative will not be permanent; it is reversible because of upward VOC vapor-phase diffusion and the resulting treated soil recontamination from the DNAPL-impacted ground water in the saturated bedrock. As discussed in Section 2.5 and Appendix E, bottom sealing to prevent VOC vapor migration and soil recontamination is not practical. The long-term carcinogenic risk associated with this alternative is less than EPA's target risk range.

Reduction of Toxicity, Mobility or Volume

This alternative will remove most of the VOC mass remaining in the unsaturated lagoon area soils. The VOCs removed by the LTTD unit will ultimately be destroyed, thereby eliminating the toxicity and volume of the contaminants. However, the mass reduction achieved by this remedy is estimated to be a small percentage of the total VOC mass present in bedrock and ground water. Also, the process of recontamination will partially offset the reduction in contaminated VOC mass achieved through LTTD.

Short-term Effectiveness

The on-site construction activities associated with the LTTD alternative can be completed in 10 to 12 months. Site disturbance associated with soil excavation and feed preparation is a source of fugitive dust and increased VOC emissions. Emissions from feed preparation activities will be captured under an enclosure. The short-term carcinogenic risk associated with this alternative is less than $4x10^{-5}$, which is within EPA's target risk range. Activities associated with excavation and soil handling present additional worker safety concerns.

Implementability

LTTD units with various capabilities are available and have been used at many sites. Before a full-scale operation can be designed, pilot trial runs will be required to verify the process performance, to adjust the unit operating conditions, and to support the required permits and approvals. The treatment process will not involve significant technical difficulties, with the exception of equipment layout decisions. Site workers under the enclosure will require a high level of protection and monitoring. To protect the local residents, air quality will be monitored during soil excavation.

At a processing rate of 1,000 tons per week, the total soil volume may be treated in about 20 weeks or 5 months. Considering the time required for site preparation, backfilling, soil cover and potential delays, the estimated construction schedule for this alternative is 10 to 12 months. The total schedule required to implement this remedy is about 36 to 38 months, including 8 months for predesign testing, 12 month for remedial design and agency approval, and 6 months for contractor selection, mobilization and permitting.

Cost

Table G-4 (Appendix G) presents the estimated cost for the LTTD alternative, based on an assumed 30-year operation and maintenance period. Total estimated costs are:

- Total Capital Cost $7,135,000 to $9,293,000
- Present Worth O/M Cost $715,000
- Total Project Cost $7,851,000 to $10,008,000

3.2.5 *Alternative 5 - Off-Site Incineration/Disposal*

3.2.5.1 *Description*

This alternative includes excavation of lagoon area soils, off-site transportation of excavated soil by rail to an off-site facility, off-site incineration/disposal, backfilling the excavation area with imported soil, and installation of a soil cover. Specific steps of this alternative include the following:

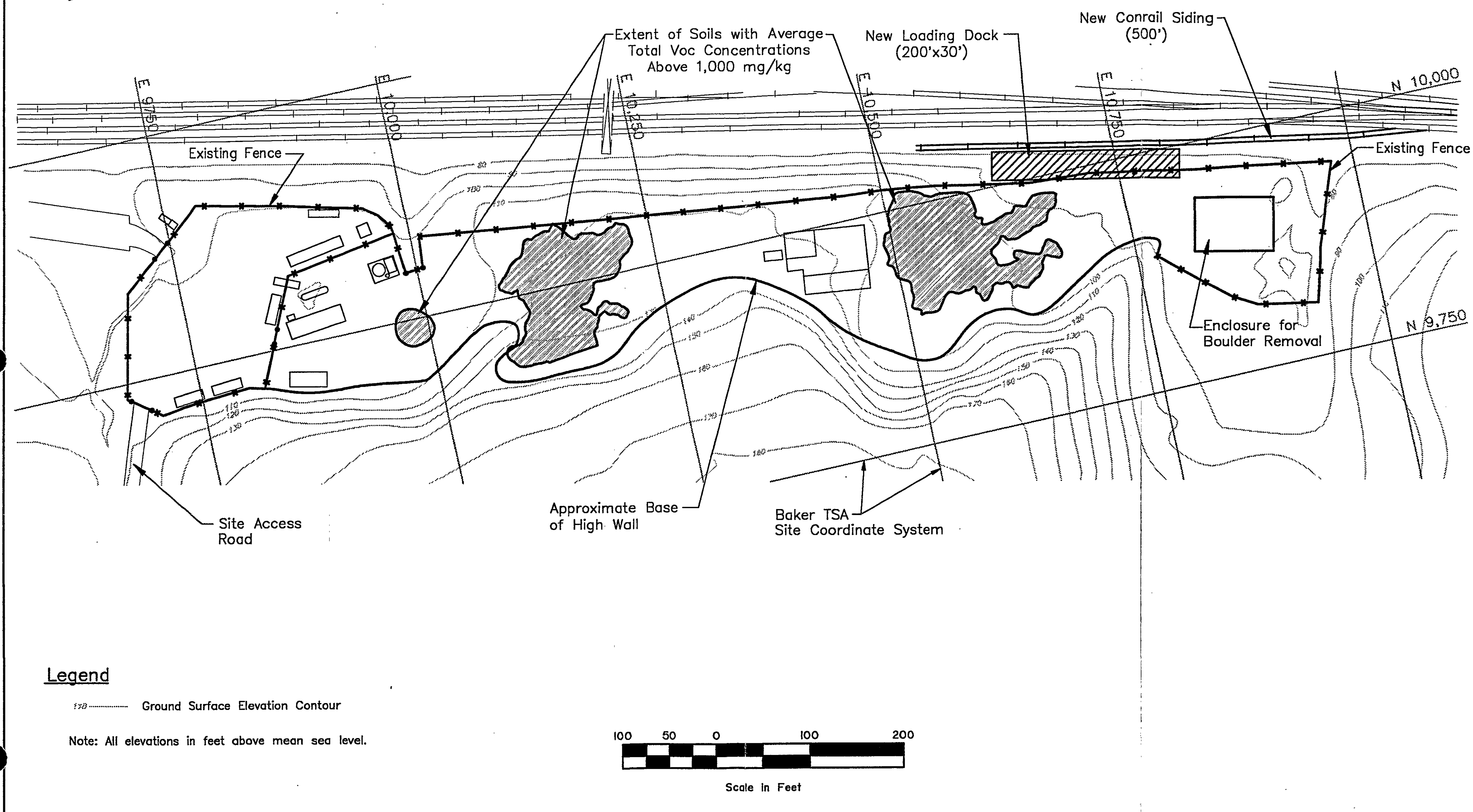
- Construction support zones and facilities.
- Remove the existing SVE wells and pipes as necessary.
- Construct a rail siding and a loading dock (Figure 3-7).
- Install an enclosure next to the rail siding for emissions control during screening and loading.
- Remove soil from the lagoon area by open excavation.
- Remove boulders from excavated soil via screening with a grizzly under an enclosure.
- Fill roll-off boxes with excavated soil for rail shipping in the enclosure.
- Load the roll-off boxes onto the rail car using a crane.
- Transport the soil to an off-site incinerator and/or land disposal facility.
- Process the soil at an off-site facility as required to meet the land disposal requirements.
- Backfill the excavation area with imported clean soil.
- Remove the siding and the loading dock, and install a soil cover over the entire lagoon area (as described in Section 3.2.1).
- Institutional controls over the site area to include upgrading the site fence and implementing deed restrictions and/or easements.

Figure 2-2 shows the general extent of excavation. Based on the evaluations discussed in Section 2.5, soils with average total VOC concentrations in excess of 1,000 mg/kg (about 13,070 cubic yards or 19,600 wet tons) will be excavated for off-site incineration/disposal. The site conditions after completion of this remedy will be similar to those shown on Figure 3-1.

Rail transportation of excavated soil is a critical requirement for off-site shipping; trucking a large volume of contaminated soils along the developed residential and commercial streets in the vicinity of the site is considered unacceptable (ERM, 1987a). Therefore, the off-site facility should have rail car off-loading capabilities. The actual facility to be used will be selected during the design and bidding phase of the project.

Soil excavation and processing to remove large boulders and cobbles will be accomplished as described previously for the LTTD alternative. Soils may be excavated and containerized at a rate of about 400 tons per day based on an 8-hour operation. However, the rail car loading rate is estimated to be about 200 tons a day, based on the roll-off box load of 20 to

Figure 3-7
Site Plan for Off-Site Incineration Alternative
Tyson's Site
Focused Feasibility Study



25 tons (using 20-cy capacity boxes), five roll-off boxes per rail car, and two rail cars per day.

Because the site is located adjacent to Conrail's Abrams switchyard, shipping of excavated soils via rail using available Conrail facilities is feasible. A new railroad siding installed along the southern-most Conrail tracks and a loading dock to allow crane operation will be required.

Coordination with Conrail will be required for scheduling of rail car services, loading, and transportation. Each day, two rail cars will be delivered to the new siding by Conrail. A trailer truck will move the roll-off boxes filled with soil to the loading dock. A crane will load the rail car with the filled roll-off boxes as they are delivered to the loading dock. Once two rail cars are loaded, Conrail will move the loaded rail cars to the storage track and deliver two rail cars with empty rolloffs to the siding. Conrail will schedule transportation of these loaded rail cars to the treatment facility.

3.2.5.2 *Alternative Evaluation*

Overall Protection of Human Health and the Environment

After implementation of this remedy, the imported backfilled soil will not contain any hazardous organic chemicals, thereby reducing VOC emissions and eliminating direct contact and ingestion risks from the areas of excavation and backfilling. However, as discussed for LTTD (Section 3.2.4.2) the clean backfilled soil will be recontaminated via vapor-phase migration which partially offsets the risk reduction gained by soil removal and treatment. The total carcinogenic risk associated with this alternative, is less than 6×10^{-5} which is within EPA's target risk range.

Compliance with ARARs

There are no chemical-specific ARARs for this project, and this alternative will not violate any location-specific ARARs. Various permits and/or approvals will be required for the implementation of this alternative (e.g., transportation of hazardous materials, erosion and sedimentation controls, etc.). This alternative is expected to comply with all action-specific ARARs including land disposal restrictions.

Long-term Effectiveness and Permanence

Although the VOC mass removed from the soil by this alternative is permanent, the treatment level achieved at the site by off-site incineration/disposal will not be maintained due to recontamination. Such recontamination cannot be practically prevented by bottom sealing methods, as discussed in Appendix E. The long-term carcinogenic is within EPA's target risk range.

Reduction of Toxicity, Mobility or Volume

This alternative will remove most of the VOC mass remaining in the unsaturated lagoon area soils. The VOCs will ultimately be destroyed through incineration, thereby eliminating the toxicity and volume of the contaminants. However, the mass reduction achieved by this remedy is only a small percentage of the total VOC mass present in the bedrock and ground water. Also, the process of recontamination will partially offset the reduction in contaminated soil volume achieved through incineration.

Short-term Effectiveness

The on-site activities required for implementation of this alternative are estimated to take 8 to 10 months. Emissions from soil processing and loading operations will be captured under an enclosure. Soil excavation will include appropriate measures to control vapor emissions from the open excavation as discussed in Appendix C. The short-term carcinogenic risk associated with this alternative is less than 4×10^{-5}, which is within EPA's target risk range. Activities associated with excavation and soil handling present additional worker safety concerns.

Implementability

Commercial off-site incinerators and off-site landfills with rail car unloading capabilities are available at several locations throughout the U.S. Incineration has been used for many projects dealing with soils, and off-site landfilling can provide secure containment of contaminated materials. Therefore, incineration and landfilling are feasible from technical and commercial availability standpoints.

Site workers under the enclosure will require a high level of protection and monitoring. To protect the local residents, air quality will be monitored during soil excavation.

At an average shipping rate of approximately 1,000 tons per week, the total soil volume may be shipped in about 17 weeks or 4 months. Including the time required for site preparation, rail siding and loading dock construction, backfilling, capping and other delays, the construction schedule for this remedy is about 8 to 10 months. The total schedule required to implement this remedy is about 29 to 31 months, including 15 months for design and agency approval, and 6 months for contractor selection and mobilization.

Cost

Table G-5 (Appendix G) presents the estimated cost for the off-site incineration remedy, based on an assumed 30-year operation and maintenance period. Total estimated costs are:

• Total Capital Cost	\$21,084,000 to \$25,919,000
• Present Worth O/M Cost	\$715,000
• Total Project Cost	\$21,799,000 to \$26,634,000

3.3 *COMPARATIVE EVALUATION OF ALTERNATIVES*

In Section 3.2, each alternative was evaluated in detail against the required CERCLA evaluation criteria. To provide the basis for the recommendation and selection of the most appropriate remedial alternative for the lagoon area soils, this section provides a comparative analysis of the remedial alternatives considered.

3.3.1 *Overall Protection of Human Health and the Environment*

Each of the remedial alternatives generally meet the established remedial action objectives, and achieve carcinogenic risks within or below EPA's target risk range (i.e., $1x10^{-4}$ to $1x10^{-6}$) as presented on Table 3-1. By effectively controlling VOC emissions and direct contact exposures, the Capping and Wet Soil Cover alternatives achieve the greatest total risk reduction, and thus provide the greatest overall protection to human health and the environment. It should be noted that the average potential risks presented on Table 3-1 are more representative of realistic conditions than the very conservative RME risk discussed in this report.

3.3.2 *Compliance with ARARs*

There are no chemical-specific or location-specific ARARs of concern identified for this project. Also, all alternatives include the appropriate measures to ensure that all action-specific ARARs and TBCs are satisfied. Thus, all remedial alternatives considered in this FFS will comply with all ARARs and TBCs identified.

Table 3-1 Summary of Estimated Risks for Remedial Alternatives

Total Carcinogenic Risk †	Alternative 1 Soil Cover		Alternative 2 Capping				Alternative 3 Wet Soil Cover		Alternative 4 LTTD		Alternative 5 Off-Site Incineration/Disposal	
			Without Venting		With Venting							
	Average	RME	Average	RME	Average	RME	Average	RME	Average	RME	Average	RME
Off-Site Resident	$1x10^{-5}$	$3x10^{-5}$	$2x10^{-6}$	$5x10^{-6}$	$2x10^{-7}$	$4x10^{-7}$	$1x10^{-7}$	$2x10^{-7}$	$3x10^{-5}$	$6x10^{-5}$	$3x10^{-5}$	$6x10^{-5}$
Maintenance Worker	$2x10^{-5}$	$8x10^{-5}$	$2x10^{-6}$	$1x10^{-5}$	$1x10^{-7}$	$6x10^{-7}$	$4x10^{-8}$	$4x10^{-7}$	$1x10^{-5}$	$7x10^{-5}$	$1x10^{-5}$	$6x10^{-5}$
Trespassing Child	$3x10^{-6}$	$1x10^{-5}$	$5x10^{-7}$	$1x10^{-6}$	$2x10^{-8}$	$7x10^{-8}$	$8x10^{-9}$	$4x10^{-8}$	$2x10^{-6}$	$8x10^{-6}$	$2x10^{-6}$	$7x10^{-6}$

Notes:

† Total carcinogenic risk = sum of inhalation, direct contact and ingestion risks; RME = reasonable maximum exposure.

3.3.3 *Long-term Effectiveness and Permanence*

Each of the remedial alternatives considered in this FFS will be effective for as long as the remedial components are maintained. The Soil Cover alternative requires minimal maintenance and allows for natural attenuation of contaminants from the lagoon area soils, but is less effective at controlling long-term VOC emissions than other alternatives. The Capping alternative is expected to provide a high degree of overall long-term effectiveness due to the ability of the clay barrier to restrict VOC emissions, and the minimal maintenance requirements. The Wet Soil Cover alternative provides for effective long-term VOC emission control and enhanced natural attenuation of contaminants, although operation and maintenance requirements are greater than for the Soil Cover or Capping alternatives. The LTTD and Off-Site Incineration/Disposal alternatives will result in permanent destruction of the VOC mass from the unsaturated lagoon area soils, but risk reduction will be partially offset by recontamination.

3.3.4 *Reduction of Toxicity, Mobility or Volume*

Operation of the SVE system over the past six years has resulted in a significant reduction in VOC mass from the lagoon area soils. It is estimated that almost 200,000 pounds of VOCs, or approximately 50% of the contaminant mass originally present in the lagoon area soils, has been removed by operation of the SVE system. In addition, SVE has preferentially removed the more volatile and more mobile constituents from the lagoon area soils.

The Soil Cover and Capping alternatives provide little additional reduction in toxicity or volume. Reduction in mobility is achieved by reducing VOC emissions and erosion of contaminated soils. The Capping alternative reduces surface water infiltration and subsequent contaminant leaching, and is more effective at restricting VOC emissions than the Soil Cover alternative. The Wet Soil Cover alternative effectively controls VOC vapor emissions, and reduces toxicity and volume through enhanced natural attenuation. By eliminating VOC emissions, the Wet Soil Cover also prevents contamination of the cover soils. The LTTD and Off-Site Incineration/Disposal alternatives provide immediate reduction of toxicity and volume through treatment, although VOC vapor migration will result in contamination of the backfilled soils. Additionally, the VOC mass reduction for the LTTD and Off-Site Incineration/Disposal alternatives is only a small percentage of the total VOC mass at the site (e.g., DNAPL in bedrock).

3.3.5 *Short-term Effectiveness*

The Soil Cover, Capping and Wet Soil Cover alternatives provide the highest level of short-term effectiveness because they can be constructed in a relatively short period of time, the short-term risks are minimal, and the benefits will be realized immediately. The short-term effectiveness of the LTTD and Off-Site Incineration/Disposal alternatives is less than for the other alternatives because of the significant soil disturbance, VOC emissions generated and associated risks, the significant health and safety requirements, and the longer implementation schedules.

3.3.6 *Implementability*

The Soil Cover, Capping and Wet Soil Cover alternatives involve available construction materials, equipment and approaches, and can be easily and quickly implemented. The LTTD and Off-Site Incineration/Disposal alternatives are moderately difficult to implement because significant volume of material must be excavated, associated engineering and health and safety controls are required, and specialized equipment, materials and approvals are needed. In addition, Off-Site Incineration/Disposal will require coordination with rail shipping concerns. A pilot study is required for LTTD prior to design activities to verify process effectiveness. A comparison of the estimated implementation schedules for each alternative is presented on Figure 3-8.

3.3.7 *Cost*

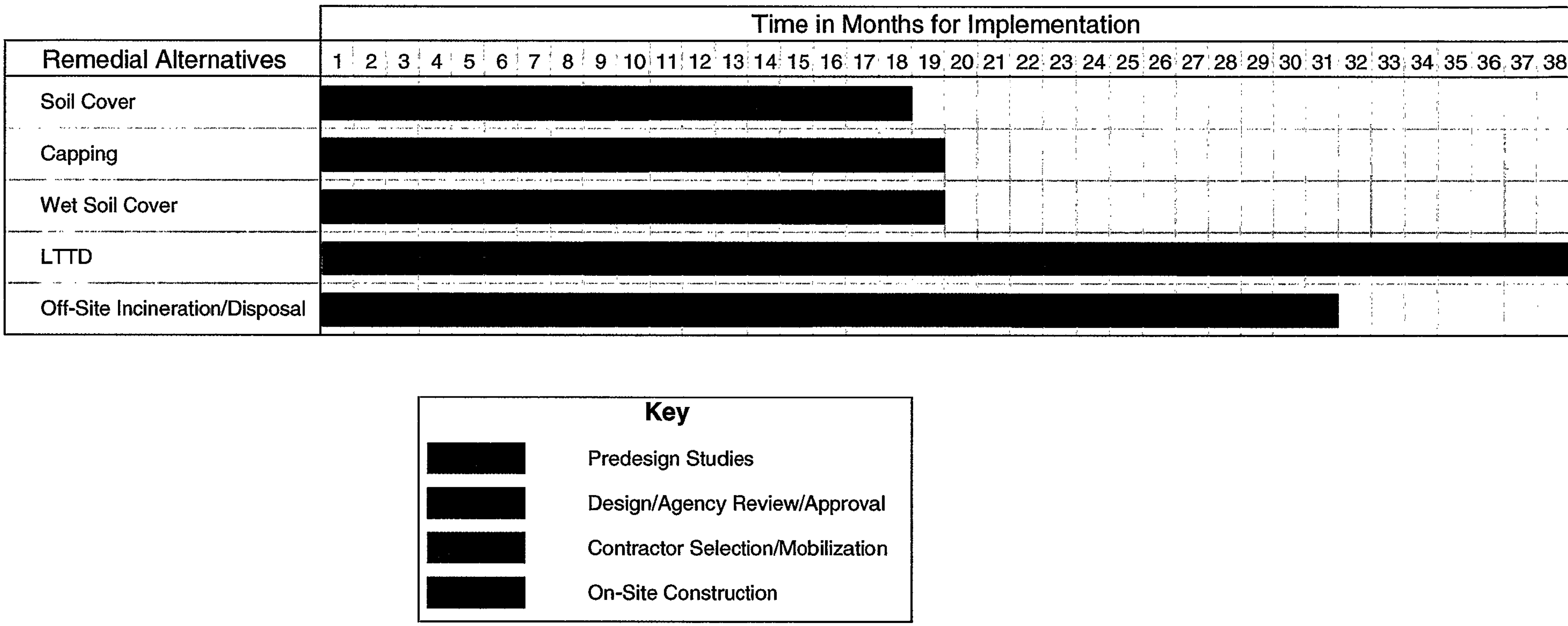
A summary of the total estimated present worth cost ranges for each alternative, assuming a 30-year O&M period, is presented below:

• Alt. 1 - Soil Cover:	$1,528,000 to $1,788,000
• Alt. 2 - Capping:	$2,350,000 to $2,746,000
• Alt. 3 - Wet Soil Cover:	$2,090,000 to $2,497,000
• Alt. 4 - LTTD:	$7,851,000 to $10,008,000
• Alt. 5 - Off-Site Incineration/Disposal:	$21,799,000 to $26,634,000

3.3.8 *Other Criteria*

As discussed previously, State and Community Acceptance will be evaluated by the EPA during the FFS approval and remedy selection processes.

Figure 3-8
Estimated Implementation Schedules for Remedial Alternatives
Tyson's Site
Focused Feasibility Study



Note:
This schedule does not include any additional site characterization.

3.3.9 *Summary*

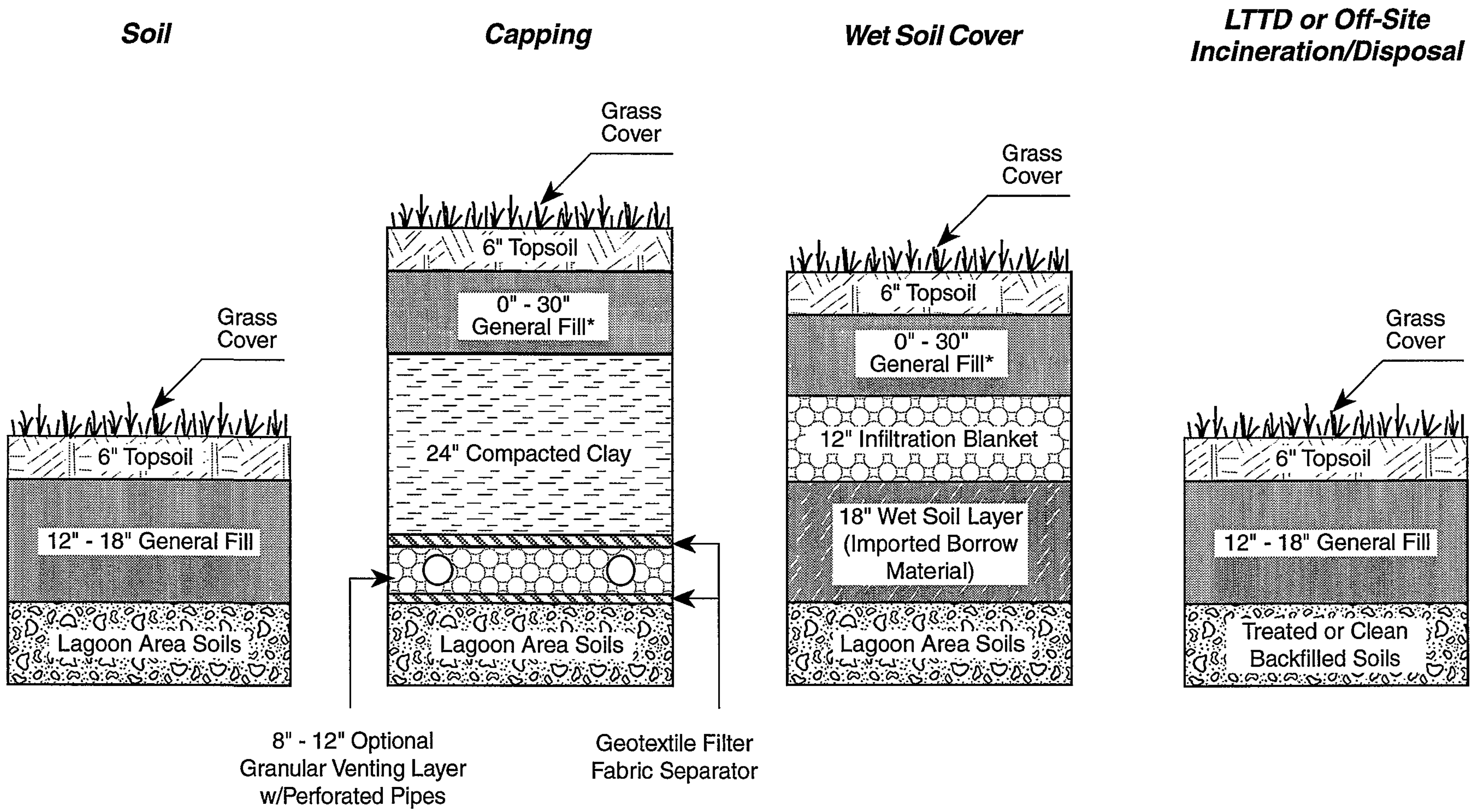
A summary of the comparative evaluation of alternatives is presented on Table 3-2. A comparison of the final covers for each of the remedial alternatives following implementation is presented on Figure 3-9. Based on the comparative analysis of alternatives, a comparative ranking of alternatives is presented on Table 3-3. This comparative ranking system was developed to provide a semi-quantitative method for comparing and ranking the relative ability of the remedial alternatives to satisfy the CERCLA evaluation criteria. In this ranking, each of the criteria was equally weighted; the overall ranking is a cumulative total of individual scores under the respective alternatives. Conclusions of the comparative evaluation of alternatives are presented in Section 4 of this FFS.

Table 3-2 Summary of Detailed Evaluation of Remedial Alternatives

	REMEDIAL ALTERNATIVES				
EVALUATION CRITERIA¥	Alternative 1 Soil Cover	Alternative 2 Capping	Alternative 3 Wet Soil Cover	Alternative 4 LTTD	Alternative 5 Off-Site Incineration/Disposal
Overall Protection of Human Health and the Environment	Carcinogenic risk ($<8x10^{-5}$) is within target range.	Carcinogenic risk is within target range without venting ($<1x10^{-5}$); risk is insignificant ($<6x10^{-7}$) with venting.	Carcinogenic risk ($<4x10^{-7}$) is insignificant.	Carcinogenic risk ($<7x10^{-5}$) is within target range.	Carcinogenic risk ($<6x10^{-5}$) is within target range.
Compliance with ARARs	Expected to satisfy all ARARs.	Expected to satisfy all ARARs.	Expected to satisfy all ARARs.	Expected to satisfy all ARARs.	Expected to satisfy all ARARs.
Long-Term Effectiveness and Permanence	Minimal maintenance, but not highly effective for long-term VOC emission control. Long-term risk is $<8x10^{-5}$.	Minimal maintenance; long-term effectiveness provided that cap is maintained. Long-term risk without venting is $<1x10^{-5}$; long-term risk with venting is insignificant.	Long-term effectiveness, provided the cover is maintained. Long-Term risk is insignificant.	Long-term effectiveness, but effects are partially offset by VOC vapor migration and recontamination. Long-term risk is $<7x10^{-5}$.	Long-term effectiveness, but effects are partially offset by VOC vapor migration and recontamination. Long-term risk is $<6x10^{-5}$.
Reduction of Toxicity, Mobility or Volume by Treatment **	Cover reduces mobility somewhat, but achieves no further reduction via treatment beyond that achieved by SVE.	Cap reduces mobility somewhat, but achieves no further reduction via treatment beyond that achieved by SVE.	Slow but steady reduction through natural attenuation. Prevents soil cover contamination.	Significant initial reduction of VOC mass from lagoon soils, but addresses only small percentage of total site VOC mass (e.g., bedrock DNAPL).	Significant initial reduction of VOC mass from lagoon soils, but addresses only small percentage of total site VOC mass (e.g., bedrock DNAPL).
Short-Term Effectiveness	Short implementation time and minimal short-term risks. Benefits are immediate. Short-term risk is insignificant.	Short implementation time and minimal short-term risks. Benefits are immediate. Short-term risk is insignificant.	Short implementation time and minimal short-term risks. Benefits are immediate. Short-term risk is insignificant.	Exposure risks are increased by soil excavation and handling. Long implementation time. Short-term risk is $<4x10^{-5}$.	Exposure risks are increased by soil excavation and handling. Long implementation time. Short-term risk is $<4x10^{-5}$.
Implementability	Can be easily and quickly implemented. ~17 to 18 Months*	Can be easily and quickly implemented. Venting requires some specialized equipment controls. ~18 to 20 Months*	Implementable, but some specialized equipment, methods and controls required. 18 to 20 Months*	Requires process verification testing, specialized equipment, lengthy design and implementation schedule, and significant health and safety measures. ~ 36 to 38 Months*	Requires lengthy design and implementation schedule, off-site transportation of a large volume of contaminated soil, and significant health and safety measures. ~29 to 31 Months*
Estimated Present Worth Cost Range (30-yr PW)	$1.5 to 1.8 Million	$2.4 to 2.7 Million	$2.1 to 2.5 Million	$7.9 to 10.0 Million†	$21.8 to 26.6 Million†

Notes:
All risks presented represent the calculated carcinogenic risks based on reasonable maximum exposure (RME) to the worst-case receptor (see Table 3-1).
*Estimated time for remedial design/remedial action.
¥State and Community acceptance are not evaluated in this FFS.
†Addresses only the unsaturated zone soils with average total VOC concentrations >1,000 mg/Kg.
**Considers that 200,000 lbs of VOCs have previously been removed by SVE operation.

Figure 3-9
Cross Sections of Final Covers for Remedial Alternatives
Tyson's Site
Focused Feasibility Study



* Thickness of general fill will depend on freeze protection requirements

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Table 3-3 Comparative Evaluation of Remedial Alternatives

	REMEDIAL ALTERNATIVES				
EVALUATION CRITERIA	Alternative 1 Soil Cover	Alternative 2 Capping	Alternative 3 Wet Soil Cover	Alternative 4 LTTD	Alternative 5 Off-Site Incineration/Disposal
Overall Protection of Human Health and the Environment	Within target range ($1x10^{-4}$ to $1x10^{-6}$), but towards high end. (3)	Within or below target range without venting ($1x10^{-4}$ to $1x10^{-6}$). (4) Insignificant risks with venting. ($<1x10^{-6}$) (5)	Insignificant risks. ($<1x10^{-6}$) (5)	Within target range ($1x10^{-4}$ to $1x10^{-6}$), but towards high end. (3)	Within target range ($1x10^{-4}$ to $1x10^{-6}$), but towards high end. (3)
Compliance with ARARs	Expected to satisfy all ARARs. (5)	Expected to satisfy all ARARs. (5)	Expected to satisfy all ARARs. (5)	Expected to satisfy all ARARs. (5)	Expected to satisfy all ARARs. (5)
Long-Term Effectiveness and Permanence	Limited VOC emission control. (3)	Effective VOC emission control. (4) Highly effective VOC emission control with venting (5).	Highly effective VOC emission control. (5)	Long-term effectiveness, but partially offset by VOC vapor migration and recontamination. (3)	Long-term effectiveness, but partially offset by VOC vapor migration and recontamination. (3)
Reduction of Toxicity, Mobility or Volume by Treatment *	No further reduction. (2)	No further reduction. (2)	Slow reduction due to natural attenuation. Prevents soil cover contamination. (3)	Significant initial reduction, but effects are offset by VOC vapor migration and recontamination. (4)	Significant initial reduction, but effects are offset by VOC vapor migration and recontamination. (4)
Short-Term Effectiveness	Short schedule and insignificant short-term risks. (5)	Short schedule and insignificant short-term risks. More effective than Soil Cover. (5)	Short schedule and minimal short-term risks. More effective than Soil Cover. (5)	Increased exposure risks and long schedule. (2)	Increased exposure risks and long schedule. (2)
Implementability	Can be easily and quickly implemented. (5)	Can be easily and quickly implemented. (5) Venting requires some specialized equipment and O&M (4).	Easily implemented, but O&M required. (4)	Requires mobilization and permitting of LTTD unit and significant excavation controls. (3)	Requires significant materials handling, transportation and excavation controls. (3)
Estimated Present Worth Cost Range (30-yr PW)	$1.5 to 1.8 Million (5)	$2.3 to 2.7 Million (5)	$2.1 to 2.5 Million (5)	$7.9 to 10.0 Million (3)	$21.8 to 26.6 Million (2)
Total Relative Score	(28)	(30 to 31)	(32)	(23)	(22)
Overall Ranking†	3	2	1¥	4	5

Notes:
*Considers that 200,000 lbs of VOCs have previously been removed by SVE operation.
Relative score for each alternative for each criterion is presented in parenthesis.
Relative score is based on a ranking scale from 1 through 5 where: 5 = best satisfies criterion; 4 = better than average; 3 = average; 2 = less favorable; and 1 = does not satisfy criterion.
† Overall ranking is presented on a scale of 1 through 5 where 1 is the most preferred alternative and 5 is the least preferred alternative based on the relative ranking.
¥ This alternative is ranked higher than Capping because it provides effective VOC emission control and allows for natural attenuation of contaminants.

AR316056

4.0 FFS SUMMARY AND ALTERNATIVE RECOMMENDATION

This section presents the recommended final remedial action for the lagoon area soils based on the evaluation and comparison of remedial alternatives conducted. To provide the basis and rationale for the recommended action, a brief summary of the critical issues identified in the FFS and the key results of the alternatives evaluation are presented below.

4.1 SUMMARY OF CRITICAL ISSUES

- It is estimated that greater than 95% of the VOC mass at the site is present as DNAPL in bedrock; this is the major source of contaminants at the Tyson's Site. The lagoon area soils contain only a small fraction of the site's contaminants and, therefore, do not present significant potential to further degrade ground water quality. Potential ground water exposures are addressed by the existing ground water recovery/treatment system, as well as the ongoing groundwater RI.

- As a result of the DNAPL in bedrock, long-term ground water remediation and monitoring are required. Thus, the selected remedy, future land use and institutional restrictions for the lagoon area soils should be consistent with the requirements and objectives of the long-term ground water remediation program. If a technology becomes available to remediate DNAPL in bedrock to the point that the lagoon area soils substantially degrade ground water quality (beyond that resulting from DNAPL in bedrock), a revised approach to addressing the lagoon area soils may be appropriate.

- An SVE system was constructed and operated for more than six years to remove VOC mass from the lagoon area soils. During this time, SVE has removed approximately 200,000 pounds of VOCs or approximately 50% of the original VOC mass in the lagoon area soils. In addition, because the SVE system has preferentially removed the more volatile and more mobile constituents from the lagoon area soils, leaving the upper few feet of soil relatively clean, VOC emissions and subsequent risk have been significantly reduced.

- In consideration of the current ground water situation, the overall remedial objective for the lagoon area soils should be to achieve acceptable risks to human health by preventing direct contact exposures and inhalation of VOC emissions from the lagoon area soils.

4.2 *SUMMARY OF EVALUATIONS CONDUCTED*

- The discussions and evaluations presented in this FFS are based on extensive engineering and scientific evaluations, detailed information and review by remediation services and equipment suppliers, bench- and pilot-scale treatability testing, and reviews of existing site information and relevant literature. These detailed studies have addressed issues such as future land use, potential remedial technologies, VOC emissions, potential health risks, excavation concerns, costs, and the other issues critical to the evaluation and selection of a remedial alternative.

- Based on the engineering and scientific evaluations conducted, a focused list of remedial alternatives was developed and evaluated. These potential remedial alternatives are grouped into the following two general response action categories:

  1. Containment (Soil Cover, Capping or Wet Soil Cover); and:

  2. Excavation (LTTD and Off-Site Incineration/Disposal).

- The evaluation conducted can be summarized by the following general conclusions regarding these response actions:

  1. The Containment alternatives (Soil Cover, Cap or Wet Soil Cover) have low implementation risks and are cost-effective approaches for reducing residual risks to within or less than EPA's target risk range.

  2. Any excavation of unsaturated soils as required for the LTTD or the Off-Site Incineration/Disposal alternatives will generate VOC emissions, and thereby result in substantially increased implementation risks. The increase in implementation risk will more than offset the incremental decrease in residual risk gained by excavation of the soils. Excavation of DNAPL-impacted soils below the water table, even if it were feasible, would further increase the implementation risk and thus negate the incremental benefit in residual risk achieved by removal.

     Additionally, VOC vapor migration would only be retarded for a short period of time until the clean fill used to replace the DNAPL-impacted soils is recontaminated by DNAPL-impacted ground water in the saturated bedrock. This will result in long-term residual VOC emissions and subsequent risk.

Thus the net result of excavation of either the unsaturated or saturated contaminated soils (as long as DNAPL is present in the bedrock) is an increase in total risk as well as remediation costs, as compared to the containment alternatives.

4.3 *RECOMMENDED REMEDIAL ALTERNATIVE AND SUPPORTING RATIONALE*

The RPs recommend the following action for the Tyson's Site lagoon area soils:

- Complete shutdown and removal of the existing SVE system;

- Implementation of the preferred Wet Soil Cover or as an alternate, Capping; and:

- Conduct a detailed engineering evaluation during the remedial design phase. As part of the engineering evaluation, the predicted performance of the wet soil cover will be compared to the more conventional clay cap described in this FFS Report. This work will establish the final engineered cover system and will be documented in a 30% remedial design deliverable for agency review and approval.

This recommendation is made in consideration of the detailed evaluation of alternatives and supporting information presented in this FFS. The rationale for this recommendation is summarized below.

- Complete shutdown and removal of the existing SVE system is recommended because continued operation will not result in significant additional VOC mass removal. Continued operation of SVE is not compatible with any of the remedial alternatives.

- It was determined through the FFS process that the Containment general response action, or specifically the Wet Soil Cover and Cap alternatives, best met the remedial goals for the site. Specific details regarding the design and operation of the containment alternatives were deferred to the remedial design phase.

- The Capping and Wet Soil Cover alternatives would both include a saturated or nearly saturated soil layer above the lagoon area soils to restrict vapor-phase diffusion and to control VOC emissions. The clay layer in the Capping alternative would have a high field capacity which would enable it to retain a high moisture content and low air-filled porosity. The Wet Soil Cover alternative would include the addition of water to maintain the upper layer of the lagoon area soils in a nearly saturated condition. The Capping alternative could include a gas venting layer which would be activated, if appropriate based on monitoring, to control VOC emissions to the design risk level, while the Wet Soil Cover alternative would utilize the downward flow of water to suppress VOC migration and virtually eliminate VOC emissions.

- Capping is very similar to the Wet Soil Cover alternative in terms of risk reduction and cost. However, the Wet Soil Cover would enhance natural attenuation of contaminants from the lagoon area soils at a slow rate. This would result in VOC removal through the addition of infiltration water and the natural movement of ground water through the underlying lagoon area soils. The Wet Soil Cover may be more compatible with future potential in-situ remediation, if such a technology becomes available.

The Wet Soil Cover is the preferred alternative based on enhanced natural attenuation, prevention of soil recontamination and compatibility with the long-term ground water program. However, final selection of either the Wet Soil Cover or Capping remedy can not be made until the remedial design phase. During this phase, the predicted performance of the wet soil cover would be compared to that of the more conventional clay cap. This evaluation would establish the final engineered cover system which best satisfies the following criteria:

- Effective long-term VOC emission control such that implementation risks are minimized and overall risks are reduced to acceptable levels;

- Minimization of contamination of additional soils;

- Compatibility with future remedial actions (i.e. would allow in-situ treatment of soils and bedrock if a technology becomes available); and:

- Cost-effectiveness.

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Appendix A
Site Characterization Report

TERRA VAC

FINAL REPORT

SITE CHARACTERIZATION REPORT
FOCUSED FEASIBILITY
STUDY SUPPORT
TYSON'S SITE
MONTGOMERY COUNTY, PENNSYLVANIA

Terra Vac Project No. 43-0032

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1.0 INTRODUCTION

Over the past five years, it has become evident that the soil vacuum extraction (SVE) remedy applied to the soils at the Tyson's Site in Montgomery County, Pennsylvania has not performed as expected. The reasons for this less than optimal performance are many and have been described in several reports prepared by Terra Vac and consultants to the Responsible Parties (RPs) for the RPs and submission to the U.S. Environmental Protection Agency (EPA). In summary, SVE performance has been limited by contaminant volalitity, soil heterogeneity, soil moisture, and the presence of DNAPLs.

In the spring of 1992, the RPs were instructed by the EPA to perform a focused feasibility study of alternative remedial strategies for the soils at the Tyson's Site. A concise description of the conditions at the site is a necessary foundation to the detailed evaluation of each remedial option. To that end, Terra Vac has developed a site description, contained in Section 2.0, based on data and experience during operations over the past five years. Included in the description of the Tyson's Site are:

- a discussion of the soil characteristics,
- a discussion of the presence of DNAPL at the site, and
- a discussion of the impact of groundwater at the Tyson's Site.

Section 3.0 presents the calculations of the various soil volumes for the site and describes the calculation methodology. Also, an iso-concentration map showing the approximate distribution of average total volatile organic contaminant (VOC) concentrations in soils at the site is included, as well as two generalized cross-sections through each lagoon illustrating the subsurface conditions. In addition, this section estimates the amount of contaminant mass remaining at the Tyson's Site based on the estimated soil volumes and calculated contaminant levels.

2.0 SITE DESCRIPTION

Initial site sampling data, collected between 1984 and 1988, indicated the existence of significant variations in the lagoon fill material, on both a chemical and physical basis, within a single borehole and laterally between boreholes. The initial chemical data commonly exhibited variations of 3 orders of magnitude within a single borehole and 7 orders of magnitude in chemical concentrations across the site. It also significantly understated the presence of DNAPL in the soils.

The contaminants routinely monitored for SVE operations found at the Tyson's Site are:

- Benzene
- Trichloroethylene (TCE)
- Toluene
- Tetrachloroethylene (PCE)
- Chlorobenzene
- Ethylbenzene
- 1,2,3-Trichloropropane (TCP)
- o- m- Dichlorobenzene (DCE)
- o- p- m- Xylene

The Tyson Site is now better understood as a result of drilling several hundred borings within the area and the installation of a number of horizontal wells. The horizontal wells also serve as horizontal pressure/vacuum lysimeters for the recovery of moisture from the soils, in addition to extracting VOCs.

2.1 Soil Characteristics

The lagoon fill is highly variable with respect to grain size, ranging from clay to sand, with numerous fragments of sandstone. The clay layers frequently contain DNAPL. Initial sampling frequently logged the lagoon fill as sand; however, more detailed, adjacent sampling commonly indicates a much higher percentage of fine-grained material. This is documented in the October 1991 Terra Vac report "Alternative Sampling Episode Results."

The soils at the Tyson's Site are extremely heterogeneous. This heterogeneity is due to variations in the physical and chemical characteristics of the soils. These characteristics vary vertically and laterally within the soil. The heterogeneities are the result of changes in grain size, permeability, soil compaction, contaminant concentrations, water content, and the physical structure of the soil layers.

Sheet 1, provided in the attached pocket, shows maps of the eastern and western portions of the site. The average total VOC concentrations in the soils are mapped in increments of 10, 1,000, 3,000, 5,000 and 10,000 ppm. The 10 and 10,000 ppm increments were used to develop the volume estimates shown in Tables #1, #2 and #3. The contours represent average total VOC concentrations in soil from the ground surface to the top of bedrock based on previous sampling events and data gathered during vacuum extraction well installation. Soil volume and VOC mass estimates determined by dividing the site into 39 slices based on mean sea level (MSL) elevations are shown in Tables 4 and 5.

Sheets 2 and 3 are cross-sections of the Upper East (A-A') and Upper West (B-B') Lagoons, respectively. These cross-sections are schematic representations of the inferred subsurface conditions in each lagoon. The cross-sections are based upon the data collected during the installation of the vertical vacuum extraction wells, the results of the alternative soil sampling program, and observations made during the installation of the horizontal trench wells.

Previous backhoe excavations in the East Lagoon have disclosed the widespread existence of a layer of man-placed boulders within the waste material. As reported in Terra Vac Semiannual Report No. 2, dated October 4, 1991, these boulder layers are underlain by DNAPL saturated soils. It appears that the boulder layers were relatively impermeable and armored the underlying waste during past vacuum extraction efforts. Sheets 2 and 3 give an interpretation of the configuration of these boulder layers.

It is important to note that the subsurface representations on Sheets 2 and 3 do not correlate directly to the lines of cross-section (A-A' and B-B') on Sheet 1. The cross-sections are intended to show an interpretation of the subsurface conditions. The actual location of the DNAPL-saturated soils may or may not coincide with the locations shown on the cross-sections.

2.2 DNAPL

In relation to SVE, the site soils contain deposits of DNAPL-saturated soils which have physical and chemical factors, in addition to high VOC concentration levels, that limit the attainment of the desired clean-up levels by producing zones of diffusion-limited processes. Operation experience demonstrates that these zones as they relate to vacuum extraction, are defined by:

1) the presence of DNAPL-saturated soils that limit the volatilization and extraction of VOCs,
2) fine-grained layers which limit air flow,
3) relatively impermeable boulder layers prevented air flow through underlying contaminated soils,
4) the interbedding of coarse (higher permeability) and finer grained (lower permeability) layers that also channel air flow.

Based on the information obtained from soil sampling and analysis, it is obvious that many locations within the Tyson's Site contain DNAPL-saturated soils, including visibly evident organic material filling interstitial voids in the soil. In discussions with field personnel, it appears that layers of DNAPL-saturated soils occupy the northern half of the West Lagoon, at depths below two feet.

In addition, the Upper East Lagoon contains at least two essentially continuous layers of DNAPL-saturated soils. These layers occur below blocks of quarried sandstone that apparently were placed in the Upper East Lagoon to provide a working surface on the low bearing strength soils. Small-interval samples of the DNAPL-saturated soil layers contain concentrations of tens to hundreds of thousands of ppm of organic material.

Soil contaminated with DNAPL occurs through the Tyson's Site, as a widespread layer on the rock/soil interface, as discrete layers within and below the recently detected rock layers, and as discrete "nuggets" of saturated soil in otherwise low-contamination areas. Such behavior is consistent with reported waste-disposal procedures. These occurrences are illustrated conceptually on Sheets 2 and 3 of Drawing 43-0032.

The occurrence of DNAPL is generally associated with fine-grained soils at the site. The presence of DNAPL further reduces the permeability of such material by filling the pore spaces, thereby retarding remediation by conventional vacuum extraction methods.

2.3 Groundwater Impact

The effectiveness of the SVE remedy has also been adversely impacted by the variable occurrence and lateral migration of soil moisture. While earlier sampling indicated the presence of saturated conditions in certain areas of the site, it is obvious that the migration of moisture in fine-grained materials was not fully appreciated or understood. It is also likely that the influence of groundwater saturated soils throughout the site has been underestimated. This variable moisture content in the soils is an important factor in the effectiveness of many remediation technologies.

Soil moisture in the unsaturated zone is held by capillary forces, specifically, tensile stress, in the pore spaces of the soil at less than atmospheric pressure. Since the pore spaces in fine-grained soils are smaller than those of coarse-grained soils, fine-grained soils generally have greater tensile stresses than coarse-grained material. Thus, the fine-grained soils, under tensile stress receive fluid from the coarse-grained, fractured sandstone, even if no actual saturated condition exists.

The SVE process significantly modifies the stress pattern within fine-grained soils by causing the capillary forces to overcome atmospheric pressure, resulting in the lateral migration of fluids. The infiltration of rainfall and snowmelt exacerbates such migration by the development of interflow into the upper portion of the fractured bedrock.

Lateral interflow from the bedrock into the soils is a major potential migration pathway, even with the best of caps and dewatering. At the Tyson's Site, the influence of groundwater flowing through bedrock fractures is of special consequence along the high wall of the former quarry.

Excessive moisture, in addition to and in combination with variations in soil type and the presence of DNAPL, has the potential to impact the remediation progress. The degree of impact caused by groundwater, if any, is highly dependent on what technology or technologies are used to continue the remediation of the Lagoon Area soils at the Tyson's Site.

3.0 SOIL VOLUME AND CONTAMINANT MASS ESTIMATES

3.1 Soil Volume

Maps of the ground surface and bedrock surface elevations relative to MSL were prepared using the computer mapping program, SURFER. These maps were the basis for soil volume calculations for each of the four major subdivisions and each branch area (well groupings with the same header) of the site.

Ground level and bedrock surface elevation maps were used in conjunction with the Area option of AUTOCAD, a computer-aided drafting (CAD) program to calculate the surface area of each branch. The areal extent of two-foot increments of soil thickness was then calculated for each branch area, and estimates of the soil volume for each branch determined.

The soil volumes for the branches of the East and West areas of the site are presented in Tables 1 and 2. Table 3 presents total soil volumes for the East and West areas and the calculated total soil volume for the Tyson's Site. These volume estimates were compared to those estimates obtained using the SURFER Volume option with the difference of about 6% (1,147,506 vs. 1,070,847 cubic feet). From these two methods, the average volume estimate is approximately 41,100 cubic yards.

3.2 Contaminant Mass

The total VOC mass at the Tyson's Site was calculated by two methods using Terra Vac's historic soil sampling data from 1988 (VE wells) through 1991 (EPA sampling event around selected VE wells). Initial contaminant mass estimates were calculated for three contamination levels (10 ppm, 10-10,000 ppm, and > 10,000 ppm) using SURFER-generated maps of the entire site. The average total VOC concentration data for a given wellbore was the basis for these maps. The data are principally based on chemical analyses of soil samples taken during well installation, but some visual observations of DNAPL-saturated soils are included where no chemical data is available.

The estimated soil volumes for each contamination level were used to form the following generalizations:

- the top two feet of the entire site generally has average VOC contamination levels less than 10 ppm,
- the Lower East, Lower West, and the inter-lagoon bedrock high areas (Branches BR15, BR60, and BR61) have average VOC contamination levels less than 10 ppm throughout the soil thickness,
- other areas outside the main lagoons with little VOC concentration data (BR14, BR51, BR52, & BR59) have one-half of their total soil volume at less than 10 ppm total VOCs, and,
- the two main lagoon areas, Upper East and Upper West, each have contaminant levels greater than 10,000 ppm.

The second method used to calculate VOC mass involved dividing the entire site into a series of two-foot thick slices stacked between the ground surface (top of slice) and the bedrock surface (bottom of slice) as defined by elevations above MSL. The lone exception to this division is a five-foot thick slice in the topographically lowest area (65 to 70 feet MSL of the easternmost portion of the site.

The Area option of AUTOCAD was used to calculate the new surface area of each slice in square feet. The SURFER program was then used to obtain a total VOC mass for each slice as follows:

VOC/slice = (VOC concentration) (area of slice) (thickness of slice)

A soil density of 87.2 pounds per cubic foot was assumed based on general matrices which occur at the site. Soil volume and VOC mass calculations are summarized in Tables 4 and 5 for the East and West areas of the site, respectively.

If several concentrations were available for a given well or sampling point within a small areal extent of a slice, the concentration values were either edited to reflect the most current data or were averaged if the data were for the same well. This methodology derived the most representative soil concentration value possible for each slice.

Results obtained from using this method varied from the results obtained by subtracting the ground surface elevation from the bedrock surface elevation using SURFER. The difference was ± 12.3% in the East and ± 18.6% the West.

The total VOC content of the Eastern area of the Tyson's Site, as calculated by the slice method with adjustments for error, was found to range between 137,000 and 175,000 pounds of VOCs. The total VOC content of the Western area of the site, as calculated by the slice method and with adjustments for error, was found to range between 122,000 to 177,000 pounds of VOCs.

An estimated total mass of VOCs in the lagoon area soils prior to the operation of the SVE remedy, including an adjustment for calculation error, was found to range between 259,000 and 352,000 pounds. This estimate includes a range of ± 10% to account for variability in the VOC concentrations in the soil of the site.

TABLE 1

FOCUSED FEASIBILITY STUDY
TYSON'S SITE
TERRA VAC PROJECT NO. 43-0032
EASTERN AREA

Branch Area	Total Soil Volume (Cubic Yards)	< 10 ppm (Cubic Yards)	10-10,000 ppm (Cubic Yards)	> 10,000 ppm (Cubic Yards)
BR01	2,247	325	1,760	162
BR02	89	9	62	18
BR03	465	46	305	114
BR04	695	61	481	153
BR05	216	29	129	58
BR06	206	43	149	14
BR07	620	147	436	37
BR08	1,016	184	763	69
BR09	1,717	152	1,414	152
BR10	1,585	222	973	389
BR11	1,168	121	806	241
BR12	910	137	687	85
BR13	1,354	215	782	358
BR14	1,934	967	958	9
BR15	8,890	8,890	0	0
Upper East Lagoon	12,288	1,690	8,748	1,850
Lower East Lagoon	10,824	9,857	958	9
Total East Area	**23,112**	**11,547**	**9706**	**1,859**

TABLE 2

FOCUSED FEASIBILITY STUDY
TYSON'S SITE
TERRA VAC PROJECT NO. 43-0032
WESTERN AREA

Branch Area	Total Soil Volume (Cubic Yards)	Soil Vol. <10 ppm (Cubic Yards)	Soil Vol. 10 to 10,000 ppm (Cubic Yards)	Soil Vol. > 10,000 ppm (Cubic Yards)
BR51	1,638	411	957	270
BR52	725	362	124	238
BR53	755	377	154	223
BR54	402	106	211	85
BR55	620	170	422	28
BR56	444	180	235	30
BR57	504	95	378	32
BR58	748	561	187	0
BR59	6,753	4,160	2,296	297
BR60	2,400	2,400	0	0
BR61	1,285	1,285	0	0
BR62	275	80	107	87
Upper West Lagoon	7,396	3,628	2,775	993
Lower West Lagoon	9,153	6,560	2,296	297
Total West Area	**16,549**	**10,188**	**5,071**	**1,290**

TABLE 3

FOCUSED FEASIBILITY STUDY
TYSON'S SITE
TERRA VAC PROJECT NO. 43-0032

Volume by Branch Areas	Total Soil Volume (Cubic Yards)	Soil Vol. < 10 ppm (Cubic Yards)	Soil Vol. 10 to 10,000 ppm (Cubic Yards)	Soil Vol. > 10,000 ppm (Cubic Yards)
Total East Area	23,112	11,546	9,706	1,859
Total West Area	16,549	10,188	5,071	1,290
Total For Site	**39,661**	**21,734**	**14,777**	**3,149**

TABLE 4
TYSON'S LOWER EAST AND EAST LAGOON AREA
SOIL VOLUME AND VOC VOLUME CALCULATIONS (1-22-93)

Interval (Ft. MSL)	Area (Sq. Feet)	Vol. (Cu. Feet)	Vol. (Cu. Yards)	Avg. Vol. (Cu. Feet)	Avg. Conc./Slice (ppm or mg/Kg)	Tot. Mass/Slice (Lbs./Cu. Ft)	Soil Dens. (Lbs/Cu. Ft.)	Tot. Soil Wt. (Pounds)	Tot. VOCs/Slice (Pounds)
68-70	10,655.20	21,310.4	789.3	23,290.0	2.2	0.0002	87.20	1,858,266.88	4.06
70-72	11,593.80	23,187.6	858.8	27,092.1	2.3	0.0002	87.20	2,021,958.72	4.73
72-74	12,164.16	24,328.3	901.0	163,389.3	13.4	0.0012	87.20	2,121,429.50	28.50
74-76	12,681.56	25,363.1	939.4	128,046.0	10.1	0.0009	87.20	2,211,664.06	22.33
76-78	13,415.48	26,831.0	993.7	19,993.5	1.5	0.0001	87.20	2,239,659.71	3.47
78-80	15,237.20	30,474.4	1,128.7	27,572.6	1.8	0.0002	87.20	2,657,367.68	4.81
80-82	14,219.64	28,439.3	1,053.3	26,670.1	1.9	0.0002	87.20	2,479,905.22	4.65
82-84	14,705.68	29,411.4	1,089.3	22,305.9	1.5	0.0001	87.20	2,564,670.59	3.89
84-86	18,339.48	36,679.0	1,358.5	4,888,326.7	266.5	0.0232	87.20	3,198,405.31	852.55
86-88	21,011.20	42,022.4	1,556.4	15,480,700.0	736.8	0.0642	87.20	3,664,353.28	2,699.92
88-90	16,635.96	33,271.9	1,232.3	59,450,666.7	3,573.6	0.3116	87.20	2,901,311.42	10,368.52
90-92	18,356.48	36,713.0	1,359.7	95,165,600.0	5,184.3	0.4521	87.20	3,201,370.11	16,597.40
92-94	19,181.56	38,363.1	1,420.9	109,279,333.3	5,697.1	0.4968	87.20	3,345,264.06	19,058.91
94-96	18,877.64	37,755.3	1,398.3	141,724,000.0	7,507.5	0.6547	87.20	3,292,260.12	24,717.44
96-98	18,570.00	37,140.0	1,375.6	121,963,333.3	6,567.8	0.5727	87.20	3,238,608.00	21,271.07
98-100	18,442.64	36,885.3	1,366.1	203,925,666.7	11,057.3	0.9642	87.20	3,216,396.42	35,565.74
100-102	18,196.20	36,392.4	1,347.9	87,599,600.0	4,814.2	0.4198	87.20	3,173,417.28	15,277.85
102-104	17,801.48	35,603.0	1,318.6	48,242,166.7	2,710.0	0.2363	87.20	3,104,578.11	8,413.70
104-106	15,052.88	30,105.8	1,115.0	6,119,933.3	406.6	0.0355	87.20	2,625,222.27	1,067.35
106-108	11,008.08	22,016.2	815.4	145,866.7	13.3	0.0012	87.20	1,919,809.15	25.44
TOTAL								55,035,917.89	155,992.33

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TABLE 5
TYSON'S LOWER WEST AND WEST LAGOON AREA
SOIL VOLUME AND VOC VOLUME CALCULATIONS (12-10-92)

Interval (Ft. MSL)	Area (Sq. Feet)	Vol. (Cu. Feet)	Vol. (Cu. Yards)	Avg. Vol. (Cu. Ft.)	Avg. Conc./Slice (ppm or mg/Kg)	Tot. Mass/Slice (Lbs./Cu. Ft)	Soil Dens. (Lbs/Cu. Ft.)	Tot. Soil Wt. (Pounds)	Tot. VOCs/Slice (Pounds)
82.4-92	7,131.95	69,099.5	2,599.2	INSUFF. DATA	INSUFF. DATA	INSUFF. DATA	87.20	6,025,476.40	INSUFF. DATA
92-94	10,145.28	20,290.6	751.5	36,663,666.7	3,613.9	0.3151	87.20	1,769,336.83	6,394.34
96-98	14,386.28	28,772.6	1,065.7	111,520.7	7.8	0.0007	87.20	2,508,967.23	19.45
98-100	15,808.96	31,617.9	1,171.0	237,173.7	15.0	0.0013	87.20	2,757,082.52	41.36
100-102	17,432.24	34,864.5	1,291.3	252,868.7	14.5	0.0013	87.20	3,040,182.66	44.10
102-104	18,524.44	37,048.9	1,372.2	4,732.5	0.3	0.0000	87.20	3,230,662.34	0.83
104-106	12,186.24	24,372.5	902.7	30,050.4	2.5	0.0002	87.20	2,125,280.26	5.24
106-108	8,183.72	16,367.4	606.2	16,271.8	2.0	0.0002	87.20	1,427,240.77	2.84
108-110	6,815.16	13,630.3	504.8	12,819.4	1.9	0.0002	87.20	1,188,563.90	2.24
110-112	6,131.00	12,262.0	454.1	9,9111.6	1.6	0.0001	87.20	1,069,246.4	1.73
112-114	8,982.44	17,964.9	665.4	90,184,800.0	10,040.1	0.8755	87.20	1,566,537.54	15,728.72
114-116	10,614.56	21,229.1	786.3	133,187,666.7	12,547.6	1.0942	87.20	1,851,179.26	23,228.65
116-118	12,392.60	24,785.2	918.0	215,656,000.0	17,402.0	1.5175	87.20	2,161,269.44	37,611.58
118-120	14,192.72	28,385.4	1,051.3	175,802,666.7	12,386.8	1.0802	87.20	2,475,210.37	30,660.94
120-122	16,724.96	33,449.9	1,238.9	13,048,466.7	780.2	0.0680	87.20	2,916,833.02	2,275.72
122-124	18,222.08	36,444.2	1,349.8	23,566,200.0	1,293.3	0.1128	87.20	3,177,930.75	4,110.07
124-126	15,003.12	30,006.2	1,111.3	62,799,800.0	4,185.8	0.3650	87.20	2,616,544.13	10,952.63
126-128	10,880.20	21,760.4	805.9	74,871,233.3	6,881.4	0.6001	87.20	1,879,506.88	13,057.95
128-130	6,431.08	12,862.2	476.4	30,896,000.0	4,804.2	0.4189	87.20	1,121,580.35	5,388.43
TOTAL								**44,908,631.05**	**149,526.82**

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October 31, 1994

EPA REGION III
SUPERFUND DOCUMENT MANAGEMENT SYSTEM

DOC ID 139944
PAGE # AR 316081

IMAGERY COVER SHEET
UNSCANNABLE ITEM

SITE NAME TYSON'S DUMP

OPERABLE UNIT OU 1 (1996 UPDATE)

ADMINISTRATIVE RECORDS SECTION ______ **VOLUME** ______

REPORT OR DOCUMENT TITLE FOCUSED FEASIBILITY STUDY FOR LAGOON AREA SOILS - PART 1 OF 2 (7/14/95 & 11/8/94 COVER LETTERS ATTACHED)

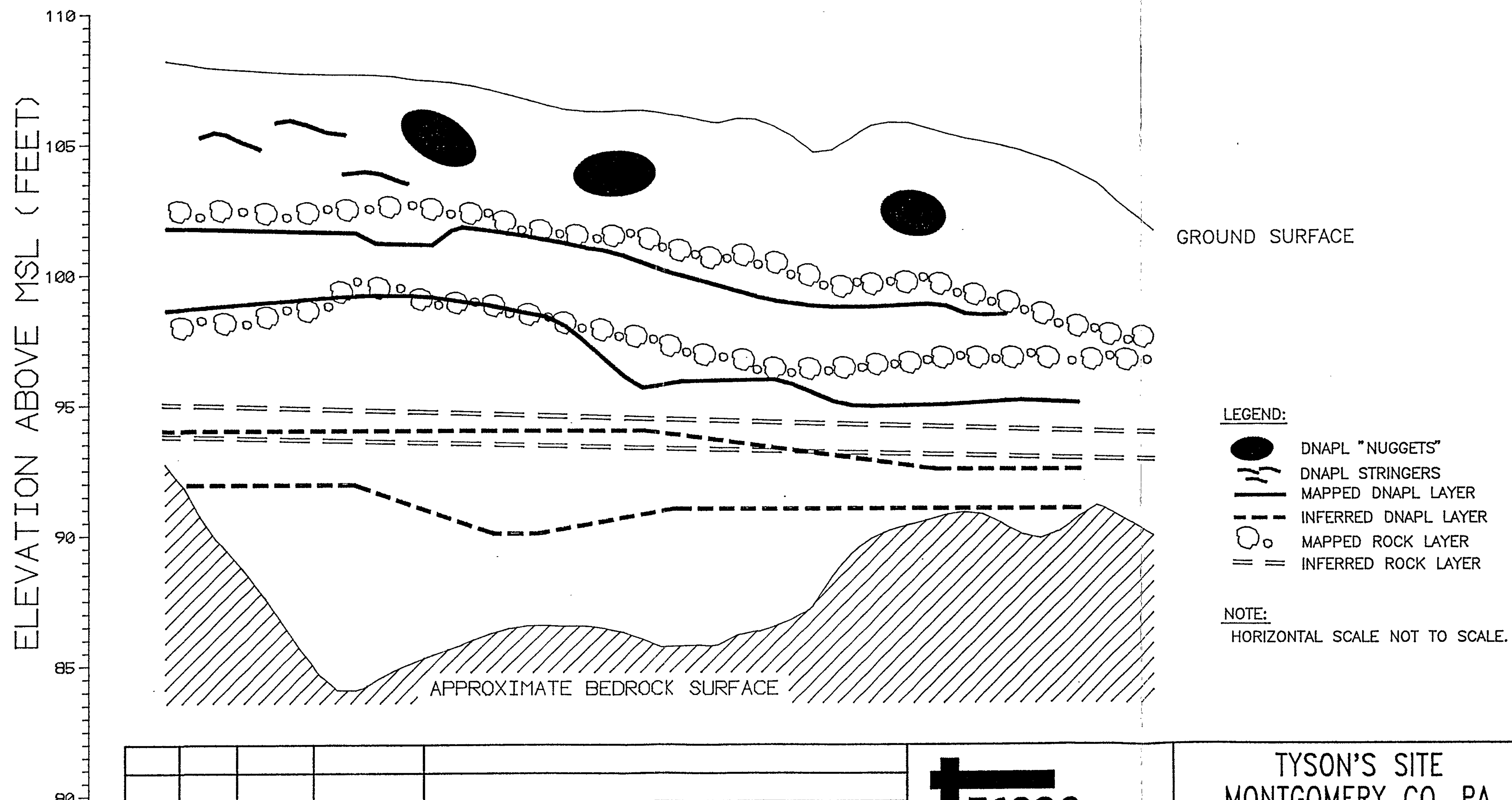
DATE OF DOCUMENT 04-NOV-94

DESCRIPTON OF IMAGERY TYSON'S SUPERFUND SITE

NUMBER AND TYPE OF IMAGERY ITEM(S) 1 OVERSIZED MAP.

TYSON'S EAST LAGOON: NORTH-SOUTH CROSS-SECTION
SCHEMATIC REPRESENTATION

(PRIOR TO 1992)



REV	DATE	MADE BY	CHECKED BY	DESCRIPTION

TERRA VAC

TYSON'S SITE
MONTGOMERY CO. PA.

N-S CROSS SECTION: EAST LAGOON
SCHEMATIC REPRESENTATION
JUNE 15, 1993

DESIGNED BY:	CHECKED BY:	DWG. NO: 43-0032	SHEET: 2
DRAWN BY: C CONNOLLY	PROJECT MANAGER:	DATE: 9/1/94	SCALE: AS SHOWN

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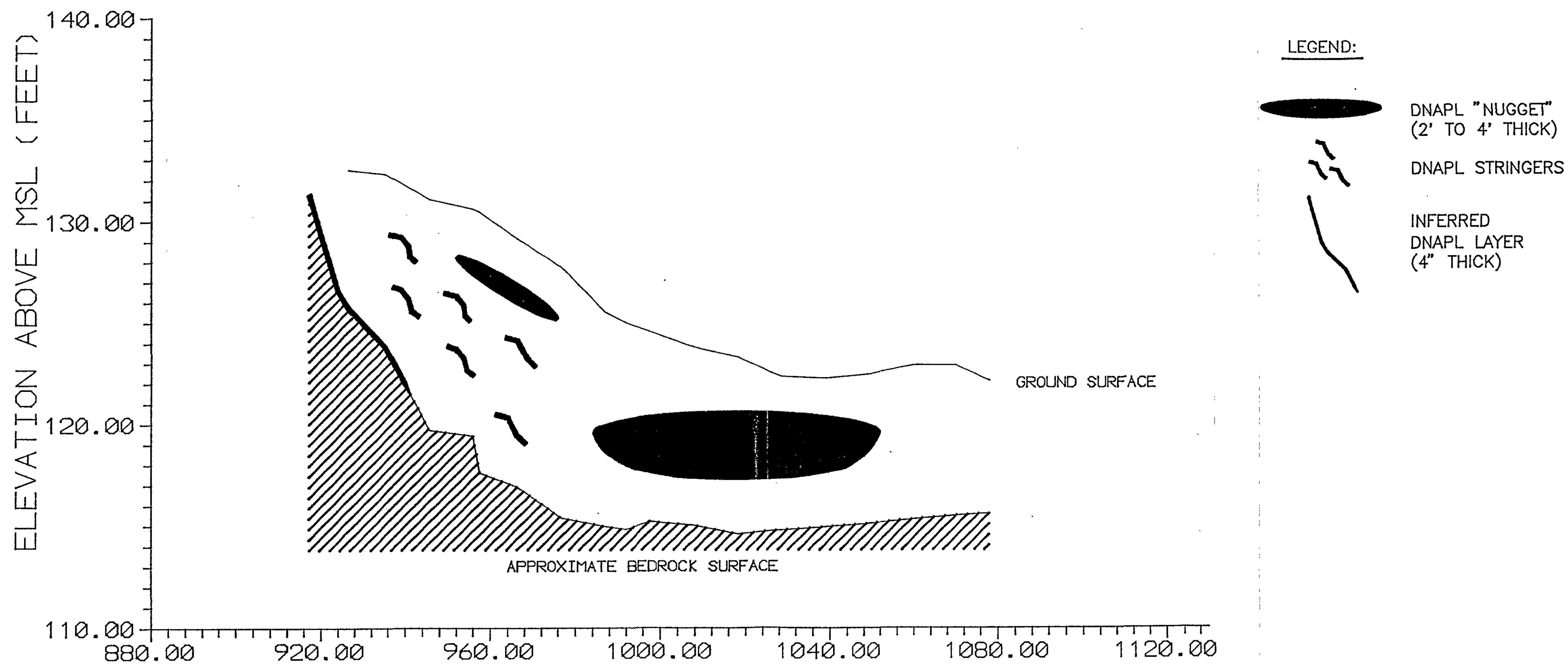
TYSON'S WEST LAGOON: NORTHEAST - SOUTHWEST CROSS-SECTION
SCHEMATIC REPRESENTATION
(PRIOR TO 1992)



REV	DATE	MADE BY	CHECKED BY	DESCRIPTION

TERRA VAC

TYSON'S SITE
MONTGOMERY CO. PA.

NE-SW CROSS SECTION: WEST LAGOON
SCHEMATIC REPRESENTATION
JUNE 15,1993

DESIGNED BY:	CHECKED BY:	DWG. NO: 43-0032	SHEET: 3
DRAWN BY: C CONNOLLY	PROJECT MANAGER:	DATE: 9/1/94	SCALE: AS SHOWN

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Appendix B
In Situ Heating and Mixing of Tyson's Lagoon Area Soils for Enhanced Contaminant Volatilization

IN SITU HEATING AND MIXING OF TYSON'S LAGOON AREA SOILS FOR ENHANCED CONTAMINANT VOLATILIZATION

September, 1994

Corporate Environmental Technology Center
Ciba-Geigy Corporation
Greensboro, North Carolina

IN SITU HEATING AND MIXING OF TYSON'S LAGOON AREA SOILS FOR ENHANCED CONTAMINANT VOLATILIZATION

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1.0 *INTRODUCTION*

Tyson's lagoon area soils are contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX), perchloroethylene (PCE), trichloroethylene (TCE), and 1,2,3-trichloropropane (TCP). Soil vapor extraction (SVE) is currently being used to remove these contaminants from the soil. The SVE process has been described by Terra Vac, the firm which designed and operates the system in place at the Tyson's Site, as follows:

> "The vacuum extraction process operates by applying a vacuum to the subsurface, creating a subsurface vacuum and pressure gradient. In situ volatilization of volatile organic compounds (VOCs) is increased, and partitioning of dissolved and adsorbed contaminants to the vapor-phase is accelerated. The vapor phase VOCs are drawn toward extraction wells by the creation of subsurface air flow through the soil matrix. This type of flow is commonly referred to as advective flow."

Although SVE has successfully removed a substantial contaminant mass from the soil, its ultimate effectiveness has been limited by several factors:

- The volatilities and sorption characteristics of the contaminants are highly varied. The more volatile contaminants, like toluene and the xylenes, are more amenable to extraction than the less volatile contaminants, like TCP.
- The contaminated soil is highly heterogeneous. Subsurface variations in permeability to air flow have complicated and hindered the SVE remedy. SVE treatment is less effective in zones containing soils with higher levels of clay and moisture content than in zones containing soils consisting mainly of silty sand. The high-moisture, high-clay soils are less permeable to air flow and tend to adsorb contaminants more strongly than the less moist, sandy soils.
- Large amounts of dense non-aqueous-phase liquids (DNAPLs) are present in the soil. The presence of DNAPL-saturated soil layers within the subsurface contributes to the soil heterogeneity problem. According to Terra Vac, virtually no pathways for contaminant transport are accessible to air flow within DNAPL-saturated zones.

In an effort to counter recent declines in SVE effectiveness, Ciba has evaluated various means to enhance the volatilization of contaminants in situ for use in combination with vapor extraction. Two basic concepts are involved:

- soil heating to increase the vapor pressure of the contaminants and the rate of mass transfer from the soil to the gas phase, and
- soil mixing to expose a greater proportion of the contaminant mass to the gas phase and to reduce subsurface heterogeneities.

Soil heating and mixing are crucial elements of low temperature thermal desorption (LTTD), a well-established ex situ treatment technology. Typically, LTTD treatment involves peak soil temperatures ranging from 400 to 1100°F.

In 1993, Ciba coordinated a laboratory screening study to evaluate application of LTTD to Tyson's Site lagoon area soils. Tests were conducted in a bench-scale rotary reactor with a number of different soil samples selected to provide a representative range of TCP concentration and soil moisture content. Target soil temperatures of 400°F, 700°F, and 1000°F were tested. TCP concentrations were measured in pre- and post-treatment soil samples. The results of this work were reported in a document prepared by Ciba entitled "Thermal Treatment of Contaminated Soils from the Tyson's Site; Focused Feasibility Study Final Report" (August, 1993).

Results from the test series in which the soil samples were held at 400°F for 60 minutes, the lowest treatment temperature tested during the study, are of greatest interest here. The TCP concentrations measured in pre- and post-treatment soil samples from this test series are listed by sample number in the table below. Samples 2 and 4 had lower initial moisture levels (approx. 12% w/w). Samples 3, 5, and 8 had higher initial moisture levels (≥30% w/w).

Sample Number	Pre-Treatment mg/kg TCP	Post-Treatment mg/kg TCP
2	129	<0.025
3	7421	1.06
4	246	0.08
5	8656	1.39
8	31,897	25.2

These data show that LTTD can achieve residual TCP concentrations on the order of 1 to 10 mg/kg even at the low end of the typical treatment temperature range, and even with initial TCP concentrations and soil moisture contents at the highest levels found in Tyson's Site soils.

In spite of LTTD's effectiveness, there are a number of problems that would impede its successful implementation at the Tyson's Site. These include limited space to accommodate soil excavation, pre-treatment, and treatment operations; control of fugitive emissions during soil excavation and handling; and the close proximity of residential neighborhoods. These and other considerations led Ciba to investigate whether some of the beneficial effects of soil heating and mixing can be achieved in situ as soil vapor extraction enhancements.

Two general in situ soil heating approaches were considered:

- chemical heating through injection of treatment reagents, and
- the injection of hot air and/or steam.

In each case, concurrent soil mixing and heating were envisioned.

The chemical heating concept involved blending quicklime (calcium oxide) or hydrogen peroxide with contaminated soil in the subsurface. Soil warming would result from the exothermic reaction of the quicklime with soil moisture, or from the exothermic reaction of hydrogen peroxide with organic matter in the soil. A laboratory screening study to evaluate this concept was performed in April, 1993 at Ciba's Corporate Environmental Technology Center in Greensboro, North Carolina.

The potential application of hot air and/or steam injection was evaluated through contact with vendors offering auger-type soil boring equipment modified for in situ site remediation. These included Novaterra, Inc. of Los Angeles, CA; Millgard Environmental Corp. of Livonia, MI; and Geo-Con, Inc. of Monroeville, PA. As an alternative to the auger-type equipment, a soil mixing system with provision for hot air injection based on conventional trench-digging technology was also evaluated. This alternative system is offered by Enviro Haz-Tech of Hegins, PA. A pilot-scale demonstration test of in situ mixing with air injection as an enhancement of SVE was conducted at the Tyson's Site in March, 1992 using Millgard mixing equipment.

Typically, the auger-type in situ soil treatment technologies noted above can achieve soil temperatures in the range of 80-95°F. Enviro Haz-Tech claims that its trench-digging system can achieve soil temperatures on the order of 200 to 250°F. These temperatures are well below the lowest soil temperature of 400°F tested during the LTTD laboratory screening study. Application of in situ mixing and heating with vapor extraction was expected to provide a significant improvement over soil vapor extraction alone, but was not expected to be as effective as LTTD in terms of contaminant removal rate and capacity to achieve low residual contaminant concentrations.

Section 2.0, below, presents brief descriptions of the specific in situ heating, mixing, and vapor capture technologies evaluated for potential application at the Tyson's Site. Section 3.0 discusses the results of the bench- and pilot-scale tests performed to evaluate these technologies, and Section 4.0 presents Ciba's current assessment of the "in situ heating, mixing, and vapor capture" treatment concept.

2.0 IN SITU HEATING, MIXING, AND VAPOR CAPTURE TECHNOLOGIES

This section summarizes the key features of four vendor technologies evaluated for possible application at the Tyson's Site involving in situ heating and mixing of soils for enhanced volatilization of contaminants. Three of these systems employ auger-type drilling equipment for soil mixing and steam or hot air injection for soil heating. One system uses trenching equipment for soil mixing and hot air injection for soil heating. In addition, all four systems include the use of shrouds placed over the treated soil surface and maintained under vacuum to collect volatilized contaminants.

2.1 NOVATERRA'S "DETOXIFIER"

The "Detoxifier," offered by Novaterra, Inc. of Los Angeles, California, is a full-scale, transportable system that uses in situ physical and chemical treatment to remediate contaminated soil. It can inject steam and hot air to strip VOCs and semi-volatile organic compounds (SVOCs), inject chemical reagents for stabilization/solidification, and/or inject oxygen and nutrients for bioremediation.

The "Detoxifier" system includes a mobile drill tower capable of performing remediation to a depth of 30 feet or more. The drill tower supports and controls a pair of hollow augers (kelly bars) which are moved vertically through the soil. The augers are rotated synchronously in opposite directions during the treatment process to break up the soil and ensure through-flow of gases. Steam at 400°F and compressed air at 275°F are piped through the augers to nozzles located on the cutter blades. An area measuring approximately 7 ft. by 4 ft. can be treated at any given time.

Heat from the injected steam and hot air vaporizes the VOCs. Volatilized contaminants are transported to the soil surface by the action of the injected fluids. A steel shroud measuring 10 ft. by 6 ft. by 7 ft covers the area of soil undergoing treatment. The area underneath the shroud is kept under vacuum to assist the flow of gases from the soil and to prevent fugitive emissions.

Process off-gases collected in the steel shroud are treated to remove particulate matter and organics in a gas cleaning system consisting of the following major equipment items:

- a wet scrubber,
- a cyclone separator,
- a cooling system,
- a carbon adsorption system, and
- compressors.

The wet scrubber removes particulate matter entrained in the process off-gases. The cyclone separator removes water droplets introduced by the wet scrubber and formed from condensed steam. The scrubbed off-gases then pass through a three-stage heat exchanger system which removes VOCs by condensation. The cooled gas stream then passes through a carbon adsorption system to remove organics not condensed in the cooling system. The gas stream exiting the carbon adsorber is drawn through the intake filter of a two-stage reciprocating compressor. The compressor is designed to increase the air pressure to 250 psig. This compression increases the air temperature to approximately 275°F. The compressed, heated air is then passed back through the augers to the soil.

The condensed phases generated by the gas cleaning system are treated using a four-stage separator followed by batch distillation to separate water from the organics. The condensed organics are collected and held for off-site treatment and disposal.

The "Detoxifier" treatment technology was demonstrated in September, 1989 at the Annex Terminal site in San Pedro, California under the auspices of the EPA's Superfund Innovative Technology Evaluation (SITE) program. The soil at this site was contaminated with chlorobenzene, trichloroethene, tetrachloroethene, phthalates, and other VOCs and SVOCs. The SITE Demonstration showed that:

- Removal efficiencies of the VOCs were greater than 90%.
- SVOCs were also removed, but at a lower efficiency.
- No significant downward migration of contaminants occurred as a result of treatment.
- The mixing action of the augers does not produce a homogeneous area of treatment. In fact, the treated block is very heterogeneous in nature. Chemical analyses for the volatile and semi-volatile contaminants and dye test data indicated that substantial variations occur within treated soil blocks.
- Fugitive emissions around the area being treated and from previously treated areas were low, but not negligible. The highest emissions were measured from a given block immediately following its

treatment, while the soil was still hot. It was found that placement of a 2-inch layer of clean soil over the treated soil blocks reduced fugitive emissions by over 50%.

2.2 *MILLGARD'S MECTOOL™*

Millgard Environmental Corp. of Livonia, Michigan has developed an in situ remediation system called MecTool™. It consists of soil boring and mixing tools, a hollow-stem kelly bar with an integral gas/fluid delivery system, very high-torque earth drilling equipment (capable of generating forces of up to 300,000 foot-pounds), a shroud system for containment and collection of treatment off-gases, and a computerized monitoring system for control and documentation of treatments.

According to Millgard, the MecTool™ system is capable of treating a soil column up to 18 feet in diameter to depths exceeding 100 feet in a single pass. In situ production rates of 100 cubic yards per hour are possible depending on the soil/sludge conditions and treatment method. Like Novaterra's "Detoxifier," the MecTool™ system was designed to provide a range of remedial options. These include solidification/stabilization, bioremediation, soil vapor sparging (air injection), soil washing, and construction of subsurface containment wall systems. Any pumpable reagent (such as hot air, steam, cement/flyash, grout, or bioremediation reagents) can be delivered to subsurface soils in situ.

The drilling apparatus consists of a hollow-stem kelly bar mounted vertically for rotation on a Manitowoc 3900 W crane. The top end of this drive shaft is attached with flexible hose to a pump unit through which reagent is delivered under pressure to the hollow shaft. A hollow-stem drill is attached to the bottom of the drive shaft with a hollow pipe extending along the trailing edge of each blade. This pipe has orifices for injecting fluid from the sleeve and hollow-stem shaft as the blade is rotated.

A vacuum is maintained beneath the off-gas containment/collection shroud. Typically, the off-gases are treated by carbon adsorption prior to release.

A pilot demonstration test using full-scale MecTool™ equipment was conducted at the Tyson's Site in March, 1992. The results of this test are presented and analyzed in a report prepared by Stan Feenstra of Applied Groundwater Research Limited with assistance from ERM. Mr. Feenstra's report, dated February 19, 1993, is titled "Soil Mixing/Soil Vapor

Extraction Pilot Study." See Section 3.2 below for a summary of the MecTool™ pilot test results.

2.3 *GEO-CON'S SHALLOW SOIL MIXING SYSTEM*

Geo-Con, Inc. of Monroeville, Pennsylvania has developed a "Shallow Soil Mixing System" (SSM system) which uses a single mixing auger (up to 16 feet in diameter) to perform in situ stabilization of soils or sludges to depths of 40 feet without excavation. It can also perform in situ vapor extraction with containment/collection of volatilized contaminants.

The vapor treatment system consists of a dust collector followed by in-line activated carbon treatment to capture any organic vapors. An induced draft fan is located after the carbon treatment system and exhausted to the atmosphere. The system exhaust is monitored using an in-line organic vapor detector.

2.4 *ENVIRO HAZ-TECH'S "MOBILE INJECTION TREATMENT UNIT (MITU)"*

The "Mobile Injection Treatment Unit" (MITU) process developed by Enviro Haz-Tech of Hegins, Pennsylvania consists of a modified trenching head mounted on a hydraulic excavator (track hoe). The trenching unit is equipped with rotary carbide cutting blades capable of penetrating dense, rocky soil. There is a metal hood surrounding the trenching unit drive mechanism which rides on the surface of the soil above the area being treated. Soil is drawn up by the rotating cutting blades of the trenching unit into this hood. Soil is dispersed outward from beneath the hood to either side of the trench, and below the hood downward back into the trench.

Hot air and/or hot exhaust from the hydraulic excavator engine can be injected through fittings on the top of the hood to warm the soil and to enhance contaminant volatilization. In this configuration, hot air is delivered to the hood through an insulated hose by a 5-hp Rotron blower mounted on the rear of the hydraulic excavator. Air is drawn from the trench through small ports mounted on a vacuum bar, and then through a 55-gallon granular activated carbon canister. The carbon canister outlet is connected to the suction side of the hot air blower. Alternately, hot air may be injected directly into the trench through the ports on the vacuum bar while vapors are withdrawn from the hood covering the trenching unit drive mechanism.

A pipe is mounted adjacent to the vacuum bar for delivery of reagents into the trench. These reagents may be in liquid, dry solid, or slurry form. For example, liquid reagents may be injected to enhance in situ bioremediation, while dry solid or slurry reagents may be injected for soil stabilization or barrier construction purposes.

A sealed aluminum box extends over the entire rear assembly of the trencher head (i.e., over the trenching unit drive mechanism) to improve containment of hot air injected onto soils impelled upward from the trench. This aluminum box is built around the metal hood surrounding the trenching unit drive mechanism, and is sufficiently long to cover the full extent of the trenching unit. There is also a provision to relocate the main hot air injection line from the hood covering the trenching unit drive mechanism to a point about mid-way along the length of the trencher head assembly for increased flow of hot air below the surface and into the trench.

A canopy extends outward from the aluminum box covering the trenching unit. This canopy measures 10 feet in width and consists of an aluminum framework covered with a plastic tarp. Perforated PVC pipe has been installed beneath the canopy and connected to the vacuum system. The canopy rides on the surface of the soil above the trench while in situ soil mixing is underway, and serves as a secondary containment device to minimize fugitive emissions of dust and volatilized contaminants.

Three different models of the MITU process are available:

- The "MITU Mini" model is designed to perform injection and mixing operations beneath basement floors and in contaminated areas under buildings. It can treat soils to a depth of 8 feet.
- The "MITU 10" model is capable of subsurface injection/mixing operations in situ to depths of 10 to 12 feet. This unit has some limited capability to cut through or push aside construction debris and large rocks.
- The "MITU 30" model is capable of deep subsurface injection/mixing operations in situ to a maximum depth of 30 feet. This unit is more powerful than the MITU 10 model, and is claimed to be capable of cutting through rock, concrete, and most types of piping. (The one type of piping found to hinder the MITU 30 equipment is large-diameter ductile iron pipe.)

3.0 *BENCH- AND PILOT-SCALE TEST RESULTS*

3.1 *SOIL HEATING THROUGH CHEMICAL ADDITION*

In 1993, Ciba's Environmental Technology Center performed a laboratory screening study to evaluate the potential effectiveness of in situ mixing with chemical treatment for enhanced volatilization of contaminants from Tyson's Site soils. Two chemical treatments were evaluated in this study: calcium oxide (quicklime) addition and hydrogen peroxide addition. The results of this work were presented by Robert Waldron and Dan Pardieck in a report entitled "Final Report, Laboratory Screening Studies, In Situ Mixing with Enhanced Volatilization, Tyson's Site" (July 16, 1993).

The quicklime treatment experiments were conducted in stainless steel reactors sized to accommodate up to 1.0 kg of soil, and equipped with propeller-type mixers for soil agitation. An attempt was made during each test to draw air through the mixed soil column under vacuum to simulate in situ soil vapor extraction. Whether or not air flow was successfully induced through the soil columns is uncertain. Indications varied from test to test. It is clear, however, that the headspace above each soil column was continuously purged.

Quicklime dosage levels of 10%, 15%, and 20% w/w were tested. Most of the soil warming impact stemming from reaction of quicklime with soil moisture occurred within 30 minutes of initial treatment. Peak soil temperatures ranged from 120°F to 230°F. In the intermediate test case, which involved a quicklime dosage level of 15% w/w, the peak soil temperature was about 150°F. The residual concentration of 1,2,3-trichloropropane (TCP) was 3.5 mg/kg, reduced from an initial concentration of 545 mg/kg. The overall TCP removal efficiency was 99%. In all cases, the initial TCP concentration ranged from 300 to 600 mg/kg, the residual TCP concentration after quicklime treatment ranged from 3 to 19 mg/kg, and the TCP removal efficiency ranged from 95% to 99%. For all quicklime dosage levels, the periods of maximum contaminant removal rate overlapped the periods of maximum soil temperature.

Because of the high quicklime dosage levels required to achieve adequate heat generation, and because of the technical problems associated with injecting dry quicklime reagent into the subsurface, the quicklime addition concept for enhanced contaminant volatilization in situ was deemed impractical. However, focusing strictly on measured relationships between soil temperature and treatment effectiveness, the quicklime addition test data suggest that a residual TCP concentration on the order of 10 mg/kg could be achieved using other soil warming techniques if the soil were heated to about 150•F, if soil heating were maintained for a sufficient time to produce a friable soil texture through reduced moisture content, and if the initial TCP concentration were less than 1,000 mg/kg. The requisite degree of heating would be difficult to achieve through hot air injection only, but might be possible with injection of super-heated steam. Unfortunately, steam injection for improved heating is inconsistent with the objective of reducing soil moisture content and increasing soil friability.

Only very small increases in soil temperature were produced in the hydrogen peroxide addition tests (on the order of 9 to 10 degrees F above the ambient temperature level). TCP removal efficiencies ranged from 85-89%. The extent to which measured reductions in contaminant concentrations resulted from oxidation of contaminants by the peroxide is unknown.

3.2 *SOIL MIXING/SOIL VAPOR EXTRACTION PILOT STUDY*

In March, 1992 a pilot study was conducted at the Tyson's Site to assess the use of in situ mixing of the soils to reduce the soil variability and enhance performance of the SVE remedy. The rationale behind this study, the procedures followed, and the results obtained are discussed in a report prepared by Stan Feenstra of Applied Groundwater Research, Ltd. entitled "Soil Mixing/Soil Vapor Extraction Pilot Study; Tyson's Site, Montgomery County, PA" (February 19, 1993). Mr. Feenstra was assisted in the preparation of this report by Environmental Resources Management, Inc. of Exton, PA.

The principle behind this pilot study was that one-time mixing of the soil column would create new pathways for air flow during SVE and expose a greater mass of VOCs to removal by SVE. Given that some of the zones of highest VOC concentration at the Tyson's Site have relatively low permeability to air, it was thought that mass removal rates might be increased by mixing these zones and exposing them to greater air flow.

The pilot study involved use of a small-sized version of Millgard's MecTool^{TM} remediation system outfitted with a mixing tool measuring 3 feet in diameter. The first objective of the pilot test was to determine the practicality of employing such equipment around the Tyson's Site given the relatively restricted site access and complex subsurface conditions (including the presence of rock and boulder layers). The second objective was to assess the impact of in situ mixing operations on the rate of VOC removal by SVE following mixing.

The soil mixing pilot study was conducted in a portion of the former East Lagoon close to the area of the original SVE pilot test conducted in 1986 and 1987. The target zone for the pilot test was situated in an area between three existing vertical SVE wells: VE-01, VE-02, and VE-74. The target zone measured approximately 12 ft. by 12 ft. in area and the soil thickness was about 20 ft. The target zone was selected because a) contaminant mass removal rates from the three SVE wells around the perimeter were well-documented (allowing valid comparisons of pre- and post-mixing SVE performance), b) there was clear evidence of the presence of DNAPL (providing a good opportunity for increasing mass removal rates), and c) a rock layer was expected to be present (as a test of the ability of the mixing equipment to bore through subsurface obstacles).

The small-sized MecTool^{TM} system proved capable of maneuvering as necessary at the site and boring to the required depth of 20 ft. to 25 ft. A larger-scale unit with a mixing tool diameter sufficient to achieve cost-effective treatment would probably prove less maneuverable than the small-sized unit. In most cases, the rock layers in the target zone slowed but did not prevent the advance of the borings. Three of the 32 borings made in the test area (about 10%) could not be completed to their full depth of 21 to 21.5 feet because it was not possible to penetrate a rock layer located at a depth of 6 to 7 feet in the time allocated for the pilot study. Observations during mixing and soil analyses after mixing suggested that a reasonable degree of mixing was achieved within the target zone.

As each boring was advanced, air was injected at a rate of about 100 scfm down through the drill rods and out into the mixed column of soil through a series of holes in the mixing blades. The purpose of this air injection was to assist development of air flow pathways for subsequent SVE operations following mixing. Once the mixing tool penetrated below a depth of 5 feet, no flow of injected air was observed returning to the surface through the mixed soil column into the vapor collection shroud. Below this depth the preferential pathway for the injected air appeared to be toward the SVE wells in operation at the perimeter of the test zone.

Monitoring of mass removal rates from VE-01, VE-02, and VE-74 before and after mixing indicated no significant increase in removal of total VOCs or TCP. (Mass removal rates did appear to increase while mixing was in progress, but returned to baseline levels as soon as the mixing was discontinued.) It was concluded that a one-time in situ mixing event does not provide a significant enhancement of the SVE system. It was noted that repeated or prolonged mixing might be found to have an effect in enhancing SVE, but that this type of mixing was not assessed in the pilot study.

4.0 *OVERALL TECHNOLOGY ASSESSMENT*

The discussion presented in Sections 4.1 through 4.3 evaluates in situ methods for enhanced contaminant volatilization in terms of three separate elements: soil mixing, soil heating, and VOC capture/treatment issues. Section 4.4 reviews the current status of the in situ soil heating/mixing technologies of each vendor in terms of site remediation projects currently underway and/or successfully completed.

4.1 *SOIL MIXING*

Terra Vac has recognized that soil heterogeneity limits SVE performance in the Tyson's Site lagoon area soils (Terra Vac, June 14, 1993). This factor, among others, is responsible for the diffusion-limited asymptotic SVE removal rates eventually experienced at the site. All of the in situ auger technologies evaluated would break up the soil to agglomerate sizes as small as 1/2" in diameter and provide localized homogenization. The augers were not designed to pass through the layers of boulders known to exist in the lagoon areas (Terra Vac Drawing No. 43-0017-5, April, 1992; Terra Vac Drawing No. 43-0017-6, April, 1992; Terra Vac Drawing No. 43-0032, June 15, 1993; and Terra Vac letter from R. Michael Peterson, Ph.D. to Ms. Kimberly A. Smith of Ciba-Geigy Corporation dated November 23, 1993). In general, the augers can handle cobbles up to 10" in diameter. Based on site demonstration results, a 10% - 20% refusal rate is anticipated due to impenetrable boulder layers or clusters.

Problems may arise with the irregularly-sloped bedrock where it exists above the water table. Small, incremental movements of auger-type soil mixing devices might be required in these areas in order to approximate the bedrock contours.

Periodic replacement of the teeth on the leading edges of augers is expected. Both the auger and its associated vapor collection shroud must be raised and blocked for this replacement.

Smaller, more maneuverable, 2'- to 3'-diameter auger units would work better in the narrow confines of the lagoon areas. The lower power capacities of these smaller units will almost certainly result in higher refusal rates. Reductions in the soil volume treated per relocation resulting from selection of smaller auger units will significantly extend the treatment schedule.

There are other constraints arising from use of augers for in situ mixing. Drilling tower height precludes the use of an enclosure to contain fugitive emissions from the treatment process. In addition, auger drilling units cannot be employed on any grade exceeding 5 degrees. Cramped conditions on site may make it difficult to accommodate various support equipment for off-gas and residuals treatment.

As a mechanism for in situ soil mixing, Enviro Haz-Tech's MITU process offers certain advantages relative to the auger-type units offered by other vendors. The absence of a drill tower makes it easier to relocate the unit from one treatment area to the next. The trenching unit can be extended from its hydraulic excavator mounting to reach less-accessible areas on site. Because of its greater maneuverability and capacity to work around subsurface obstructions, the MITU system will likely provide a more rapid soil processing rate than the auger-type units. Because the mixing action of the MITU trenching device lifts and redeposits the soil rather than simply churning through it, greater soil homogenization in the vertical dimension can be achieved.

4.2 *SOIL HEATING*

Conventional technologies for heating soils in situ to enhance contaminant volatilization, i.e., steam and/or hot air injection, have three major limitations: slow heat up time, relatively low peak soil temperatures, and the requirement to capture the hot air injected into the subsurface.

In the case of treatment using auger-type mixing systems, the heat sink afforded by the mass of subsurface soils limits peak soil temperatures. Typically, a peak temperature range of 80 to 95 degrees F is achievable with auger-type soil mixing devices. This limitation translates into longer treatment times than those required with LTTD, which typically operates in the 400 to 1100 degree F range.

Both the time required to heat the soils and the peak temperature achievable depend largely on the heat source used. Because of its low specific heat capacity, hot air alone is a poor heat source. Only one vendor, Novaterra, uses super-heated steam to augment hot air heating. The need to heat an entire soil column and maintain it at 90 degrees F for several hours limits the soil processing rate with auger-type mixing equipment to well below that achievable with LTTD, even when the selection of LTTD equipment is limited to units with indirect heating. Given that the operating costs of LTTD and auger-type in situ heating/mixing equipment are similar, LTTD treatment's ability to heat the soil quickly and to a higher temperature makes it more cost-effective overall.

The soil heating mechanism associated with Enviro Haz-Tech's MITU system differs in significant ways from that associated with the auger-type soil mixing devices. As it cuts a trench through the contaminated soil, the MITU system essentially excavates the soil, exposes it to a concentrated blast of hot air, and then replaces it. The application of heat is localized and concentrated, and is reminiscent of direct-fired LTTD systems. The peak soil temperature achieved is still considerably lower than the lowest value associated with LTTD, as is the duration of time over which the peak temperature is maintained. Nevertheless, some of the disadvantages inherent in attempting to heat an entire subsurface soil column are avoided.

Off-gas capture capabilities may indirectly restrict the rate of soil heat-up by limiting the volume flow rate of injected hot air that can be tolerated without encountering a fugitive emissions problem. This limitation can be offset to some degree by injection of super-heated steam together with hot air. The steam will deliver more heat to the soil per unit volume, making it possible to cut back the hot air flow rate. There is a strong possibility, however, that steam injection would prove counterproductive. To the extent that some portion of the injected steam condenses within the soil column, the soil moisture content would be increased. Experience has shown that better contaminant volatilization results are achieved when the moisture content of the soil is reduced.

4.3 VOC CAPTURE/TREATMENT

The effective capture of VOC and SVOC vapors has proven to be the most serious issue of concern to emerge from Ciba's technical evaluation of in situ heating and mixing treatment technologies. None of the vendor systems evaluated adequately address prevention of fugitive emissions, even though each incorporates specific design features for that purpose.

Each auger-type soil mixing system has a shroud which is somewhat larger than the diameter of the auger. These shrouds are placed on the surface of the soil area being treated. They have been sized to accommodate the typical soil column expansion which results from the mixing process while preserving some free headspace above the soil surface. Blowers are used to draw collected vapors from the shrouds into on-site air treatment systems. These systems may include filters or scrubbers to remove entrained particulate matter, condensers to recover organic compounds, and granular activated carbon beds to collect the noncondensables.

In the process of agitating and breaking up the soil, the augers are expected to generate a preferential flow path for treatment off-gases along the auger shaft. Hot air for soil heating is injected at the lowest point of the auger and must pass through the soil column before entering the shroud.

The off-gas capture effectiveness of these systems was evaluated by reference to the results of the in situ soil mixing pilot test described above (Stan Feenstra, February 19, 1993), and through direct discussions with the vendors. Pilot testing at the Tyson's Site showed that air injected at a depth of five feet below the surface no longer passed upward through the mixed soil column and into the shroud. It is unclear, however, to what extent the flow of air was inhibited by the soil column above and to what extent it was influenced by the SVE wells in operation on the perimeter of the test zone. The preferential pathway for the air appeared to be toward the perimeter wells and not toward the soil surface. During a test performed at the Portsmouth Gaseous Diffusion Plant, one observer noted that air pockets were formed under plastic sheets placed around the shroud to prevent surface emissions.

From a theoretical standpoint, it is unlikely that the auger-type mixing system vendors can guarantee the preferred air flow pathway will be upward through the soil column. On the contrary, it is likely that some organic vapors will pass into adjacent soil columns. This flow of air into adjacent areas could potentially emerge from the soil surface, thereby creating a fugitive emissions problem. To the extent that the hot air injection rate is increased to speed the soil heating cycle, the greater is the chance that some significant portion of the contaminant-laden air will not be captured. Geo-Con and Terra Vac have proposed the use of perimeter wells to collect the vapor instead of relying exclusively on a shroud for capture. This approach would be very cumbersome to implement at the Tyson's Site.

The off-gas containment, collection, and treatment mechanisms associated with Enviro Haz-Tech's MITU system are described in detail in Section 2.4. Again, a shroud system designed to cover the area undergoing treatment and maintained under vacuum is provided for dust containment and to collect vapors emanating from the soil. In the case of the auger-type mixing systems, there is some concern regarding the emergence of air injected into the soil column from areas adjacent to the treatment zone. By contrast, the concern associated with the MITU system is that the off-gas shroud will not be able to contain the air injected onto soil within and above the trench created by the device. The same features of the MITU system which make heat transfer to the soil more efficient also make off-gas containment more problematic.

Various levels of sophistication exist among vendors with regard to off-gas treatment. Some vendors of in situ soil mixing/heating equipment have entered into partnerships with other vendors to develop appropriate off-gas treatment capabilities. The need for condensation followed by adsorption using granular activated carbon was identified early as a minimum requirement for VOC collection. Novaterra has already demonstrated such a system. Millgard has indicated it will use RUST's expertise and equipment to provide suitable off-gas treatment. (In fact, the system envisioned by Millgard is essentially identical to the system associated with RUST's LTTD unit.) Geo-Con has suggested that it could utilize the off-gas treatment equipment already in place at the Tyson's Site to treat off-gases from Terra Vac's SVE system. It also appears that this approach could be successful with Enviro Haz-Tech's MITU system. With these partnerships, adequate off-gas treatment would be achievable. In each case the recovered organics would be shipped off site for incineration.

4.4 *VENDOR QUALIFICATIONS*

Demonstrated effectiveness in the field is an important consideration in the evaluation of any site remediation technology. This section addresses the qualifications of each technology vendor in terms of its field applications track record.

4.4.1 *Novaterra*

Novaterra has completed one full-scale site remediation project using its "Detoxifier" system for in situ mixing with hot air and steam injection. This project was located at the GATX Superfund site in California, and involved the remediation of 30,000 cubic yards of soil contaminated to a depth of 10 feet with various VOCs and SVOCs (including perchloroethylene, trichloroethylene, acetone, dichloroethane, chlorobenzene, MIBK, glycol ethers, and various phthalate esters.) Individual contaminant concentrations in the soil typically varied from 10 to 5,000 ppm. Total contaminant concentrations were as high as 20,000 to 40,000 ppm. The contaminated soils were remediated to risk-based performance standards established by the California EPA. The project was completed in 1993 after more than one year of continuous treatment.

A controlled test of the "Detoxifier" system was performed at the GATX site under the auspices of the U.S. EPA's SITE demonstration program in late 1989 and early 1990.

In February 1993 a pilot-scale field demonstration was performed at Warner Robins Air Force Base in Georgia using a scaled-down version of the "Detoxifier" called the "Verifier." A peat soil with underlying clay was treated to remove 99.5% of the VOC contaminant mass (chlorinated solvents and toluene). Initial contaminant concentrations ranged from 200 to 400 ppm. Other pilot-scale field demonstrations have been completed at an FMC site in northern California (petroleum hydrocarbons and TCE), and at the Fulton Terminal Superfund site in New York (TCE and DCE).

4.4.2 *Millgard*

Millgard has performed two pilot-scale demonstrations of its MecTool™ system involving in situ soil mixing with hot air injection. As noted earlier in Section 3.2, a pilot-scale demonstration of the technology was conducted at the Tyson's Site in March 1992. This project involved the use of a small-sized version of the MecTool™ equipment. Also in 1992, a pilot demonstration utilizing full-scale equipment was performed at the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio. A 2,000 cubic test plot consisting of soil contaminated with TCE and TCA at approximately 300 ppm was treated to a depth of 22 feet. Ambient air at 100 degrees F and hot air at 280 degrees F were injected into the soil in conjunction with mixing. A 5% hydrogen peroxide solution was also injected into the soil to oxidize the contaminants. Post-treatment soil sample analyses indicated that TCE and TCA removal efficiencies in excess of 98% were achieved

4.4.3 *Geo-Con*

Geo-Con has undertaken one full-scale site remediation project using its Shallow Soil Mixing (SSM)/Thermally Enhanced Vapor Extraction (TEVE) system. This system is being used to remove VOCs (primarily TCE) from clayey soils at the Portsmouth Gaseous Diffusion plant in Piketon, Ohio. VOC contamination at the project site extends to a depth of 22 feet.

Soil mixing is performed in situ using mixing tools with diameters ranging from 8 to 12 feet. The soil is heated during mixing by hot air injection. VOCs are removed from the surface of the mixed soil column and from vapor extraction wells in the vicinity of the mixed soil column. The work plan for the project calls for 70% removal of the VOC mass.

Geo-Con claims it has completed the major portion of this project while meeting all treatment criteria.

4.4.4 *Enviro Haz-Tech*

Enviro Haz-Tech completed the first full-scale application of its Mobile Injection Treatment Unit (MITU) for in situ soil remediation with hot air injection in February 1994. Approximately 2,500 cubic yards of soil contaminated with petroleum hydrocarbons and VARSOL (a proprietary solvent consisting of a blend of mineral spirits and naphtha) were treated at a manufacturing facility in Frackville, Pennsylvania. The MITU 10 model, which has a depth range of 12 feet, was used for the project. In order to allow penetration to the maximum contaminant depth of 16 feet, the top 6 feet of clean soil was removed during the project. Contaminant concentrations ranging from 4,000 to 16,000 ppm were reduced to approximately 200 ppm or less in various treatment zones.

The larger MITU 30 model is currently performing in situ mixing with hot air injection at a contaminated site in Ohio.

Enviro Haz-Tech has also completed a project involving the above-ground treatment of a contaminated soil stockpile. A 50-ton stockpile of xylene-contaminated soil at an Ingersoll-Rand facility in Shippensport, Pennsylvania was successfully remediated in late August 1994 using the MITU 10 equipment.

In general, the application of auger-type devices with hot air or steam injection for thermally-enhanced in situ soil remediation has been extremely limited. Enviro Haz-Tech's MITU process, which employs a trenching unit in place of an auger for in situ soil mixing, has been on the market for a much shorter time. It is still too early to tell how well it will fare in establishing a niche for itself within the site remediation industry.

4.5 *CONCLUSIONS*

Auger-type <u>in situ</u> soil mixing and heating technologies suffer from numerous shortcomings which have led to their elimination from further consideration:

- inability to operate where grades exceed 5 degrees,
- inability to deal effectively with subsurface obstructions, particularly boulders,
- potentially significant schedule delays and costs associated with auger maintenance,

- operating inefficiencies associated with soil treatment in close proximity to irregularly-shaped bedrock,
- equipment and treatment area size limitations related to cramped conditions on site,
- preclusion of enclosure installation due to drilling tower height,
- limited soil heating capacity and poor cost-effectiveness relative to the LTTD treatment option, and
- inability to guarantee the prevention of fugitive emissions.

By contrast, Enviro Haz-Tech's MITU system is markedly superior in relation to most of these same issues:

- able to operate where grades are relatively steep,
- able to resposition quickly to work around subsurface obstructions,
- the trenching unit cutting teeth can be maintained without significant delays in operation,
- able to trace contours of irregularly-shaped bedrock without cumbersome repositioning,
- able to maneuver the trenching head into the least accessible areas of the site despite cramped conditions,
- capable of operating within a "sprung-structure" type enclosure, and
- soil heating capacity is intermediate between the auger-type soil mixing systems with hot air injection and LTTD.

The principal shortcoming of the MITU system is its lack of adequate means to prevent fugitive emissions. This is, however, an engineering problem that should be amenable to solution.

Until and unless a field demonstration of the MITU system is performed at the Tyson's Site, it will not be possible to complete a detailed evaluation of the technology as a full-fledged treatment alternative. A field demonstration will be the only way to determine site-specific data concerning treatment effectiveness and cost. Because of its many advantages relative to other in situ soil heating/mixing technologies, the MITU process will be retained as a treatment technology that could be evaluated with other on-site treatment technologies.

Appendix C
Soil Removal Analysis for the Tyson's Lagoon Area Soils

SOIL REMOVAL ANALYSIS FOR THE TYSON'S LAGOON AREA SOILS
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1.0 *INTRODUCTION*

The potential remedial alternatives for the Tyson's Site include treatment technologies requiring excavation of the lagoon area soils. This appendix provides the basis for selection of the quantity of soils to be considered for removal, describes the process of excavation and soil handling, and evaluates open and enclosed excavation with respect to VOC emission and control, and recommends the best approach to excavation.

The low temperature thermal desorption (LTTD) process is used to represent on-site treatment remedies and off-site incineration is used to represent off-site treatment/disposal remedies.

2.0 SOIL VOLUMES CONSIDERED FOR REMOVAL

2.1 SITE CHARACTERISTICS

The Tyson's Site is naturally subdivided by topography, soil characteristics and contamination concentrations into four areas referred to as the Lower East Lagoon, Upper East Lagoon, Upper West Lagoon, and Lower West Lagoon. It is believed that the former lagoons were originally quarry pits which were filled with soil and rock in layers as the liquid waste materials were deposited. As depicted on Figure C-1, a bedrock high separates the Upper East and Upper West Lagoon areas where the highest VOC concentrations are found. These areas are also where the unsaturated soils are deepest.

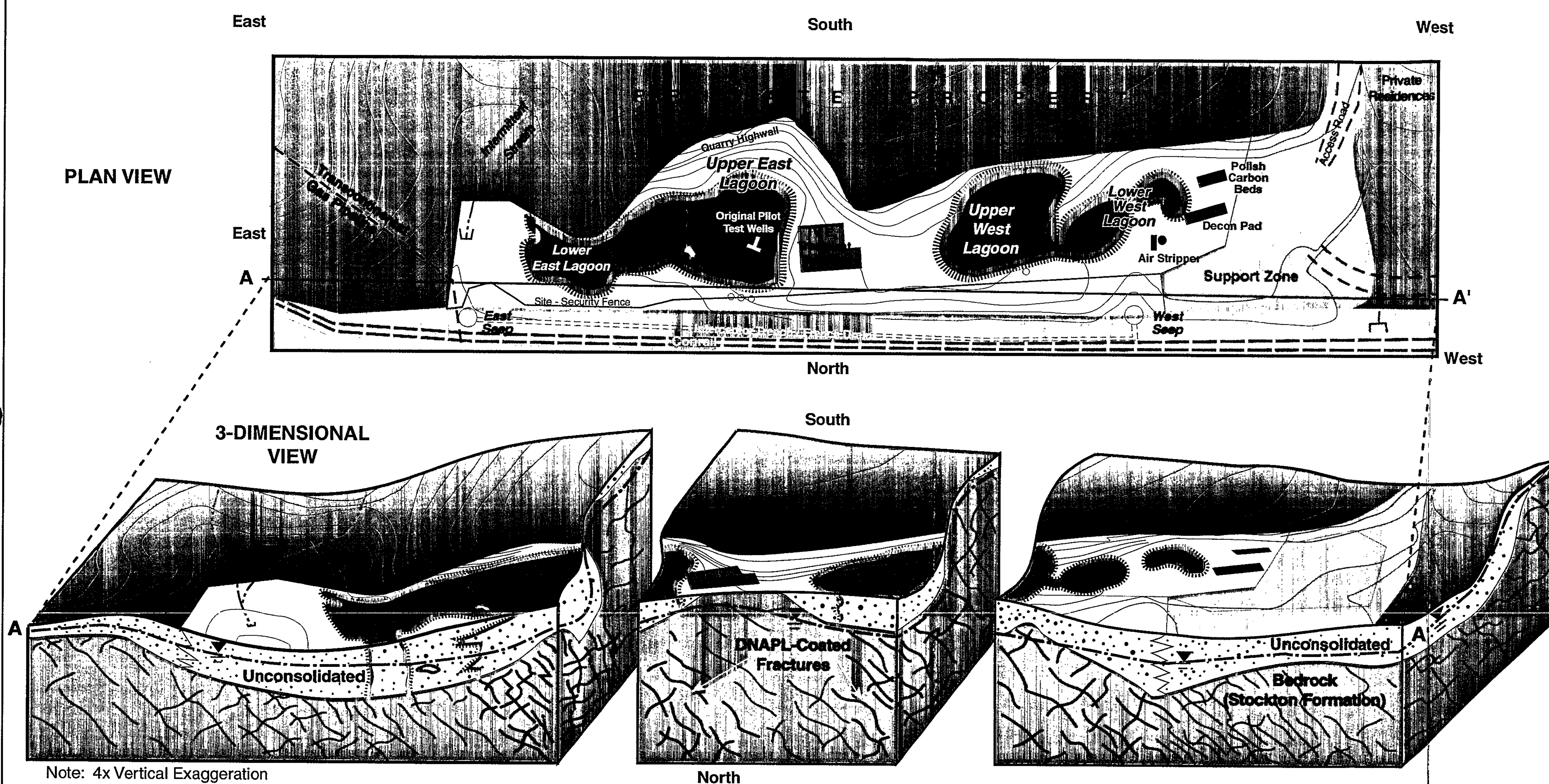
The Lower East and Lower West Lagoon areas generally exhibit lower VOC concentrations and thinner unsaturated soil horizons. Also, there is no evidence to suggest that an actual lagoon existed in the Lower East Lagoon area. The eastern portion of the Lower East Lagoon area has very low VOC concentrations, and is believed to have been contaminated by migration of soils from the former lagoon areas through surface runoff rather than direct deposition of wastes. Additionally, the existing SVE system support zone at the western end of the site is characterized as uncontaminated.

Total lagoon area soil volume has been estimated to be 41,100 cu. yd. (Terra Vac, 1994). This includes all unconsolidated lagoon area soils north of the quarry high wall and within the exclusion zone fence.

The natural ground water level in the lagoon area is such that the top of the saturated zone ranges from 4 to 12 feet below the surface (ERM 1989). Additionally, bedrock is very close to the surface at several places within the lagoon area. Excavation is assumed to extend to the top of the saturated soil zone or to bedrock when it exists above the saturated zone. Excavation of saturated soils is not included in this FFS. These soils are considered part of the ground water aquifer which is the subject of an ongoing ground water remedial investigation.

Approximately 13,200 cu. yd. of lagoon area soils is estimated to be located within the saturated zone. This assumes that half of the approximate four-foot-thick saturated capillary zone is included as part of the saturated zone. The remaining upper two-foot-thick capillary zone is considered part of the unsaturated zone.

Figure C-1
Lagoon Area Schematic
Tyson's Site
Focused Feasibility Study



LEGEND

- Approximate Areal Extent of Lagoon Area Soils
- Support Zone
- Private Property
- Conrail Right-of-Way
- Buildings

Subsurface Features

- Fractured Bedrock
- Fractured Bedrock with DNAPL-Coated Fractures (Bedding Planes and Joints)
- Unconsolidated Soils Not Impacted by Site-Related Compounds
- Unconsolidated Soils and Deposits Impacted by Site-Related Compounds
- Approximate Ground Water Level (Red when in Contaminated Soils)

0 100 200 300
Scale in Feet (Approximate)

2.2 CONTAMINANT DISTRIBUTION AND MASS ESTIMATES

The distribution of contaminants throughout the lagoon area soils is highly variable, but shows zones of high VOC concentrations which coincide with the former lagoon locations both horizontally and vertically. This contaminant distribution is illustrated in Table C-1. The highest concentrations of Tyson's Site VOCs within the unsaturated soils are found near the middle of the site (Upper East and Upper West Lagoons) and at depths below 5 ft. The upper few feet of soil is relatively clean as a result of the SVE system operation (Terra Vac, 1994).

The total mass of VOCs originally associated with the lagoon area soils is estimated to be approximately 400,000 pounds. This is an average of VOC mass estimates from ERM, 1989 (488,000 lb) and Terra Vac, 1994 (278,000 lb to 325,000 lb). Approximately half of this mass has been removed by the SVE system. Of the remaining 200,000 pounds, approximately 75 percent is estimated to be contained within the unsaturated soils (ERM 1994a).

2.3 EXCAVATION VOLUME

Saturated soils are considered part of the ground water aquifer, which is the subject of an ongoing ground water remedial investigation. However, in evaluating the depth to which excavation may be feasible, a preliminary assessment of the risks associated with excavating DNAPL-impacted soils in the saturated zone was conducted. As discussed in the Risk Assessment Report (Appendix F, page 96), a net increase in risks would result if excavation was extended beyond the unsaturated zone. This increase would be due to VOCs generated by exposing soils located at depth and within the saturated zone. Consequently, the following analysis focuses on soils in the unsaturated zone.

Approximately 99% of the VOCs in the unsaturated soils is located within the 1,000 mg/kg contour, which represents approximately 38% of the total unsaturated lagoon area soils (Table C-1). As part of the Risk Assessment Report (Appendix F, Table 34), a sensitivity analysis was conducted to compare the risks associated with 1) excavation of all unsaturated soils; and 2) select excavation of soils with average VOC concentrations greater than 1,000 mg/kg. Although the implementation risk is approximately equal under the two scenarios, no reduction in residual inhalation risk is realized by excavating all of the unsaturated soils. This is due to the fact that residual risks are driven by the upward diffusion of vapors from DNAPL in the bedrock and ground water.

Therefore the volume of soils on which the excavation alternatives are based is unsaturated soils containing average VOC concentrations of 1,000 mg/kg or greater. This estimated soil quantity is 13,070 cu. yd. It includes 2,470 cu. yd. of adjacent soils with VOC concentrations less than 1,000 mg/kg which will have to be removed to allow excavation of higher contaminant levels at depth.

Table C-1
VOC Distribution in Unsaturated Lagoon Area Soils(1)

Total VOC Concentration Ranges (mg./kg.)	<u>≤10 ppm</u>	10 to <u>1,000 ppm</u>	1,000 to <u>10,000 ppm</u>	>10,000 <u>ppm</u>
Total Soil Volume (cu. yd.)	10,940	6,350	5,470	5,150
West Lagoon Soil Volume (cu. yd.)	3,190	2,070	1,020	2,480
East Lagoon Soil Volume (cu. yd.)	7,750	4,280	4,450	2,670
Estimated. Average. VOC Concentration. (mg./kg.)	1	108	1,070	10,700
Total Soil Mass(2) (tons)	13,130	7,620	6,580	6,180
Total VOC Mass (tons)	0.01	0.82	7.04	66.13
Percent of total VOC Mass	0.01	1.1	9.5	89.4

(1) VOC distribution based on data provided in the TerraVac Site Characterization Report, (Appendix A) and reflects an average of samples collected at various depths and at different times during operation of the SVE system.

(2) Based on an assumed dry soil density of 1.2 tons/cu. yd. (90 pcf).

3.0 EVALUATION OF EXCAVATION AND MATERIALS HANDLING

3.1 EXCAVATION METHODS

Soil removal will be accomplished by mechanical excavation. The maximum excavation depth is 12 feet. An excavation area of 360 $ft.^2$ represents the smallest practical excavation size.

3.2 SOIL PRETREATMENT

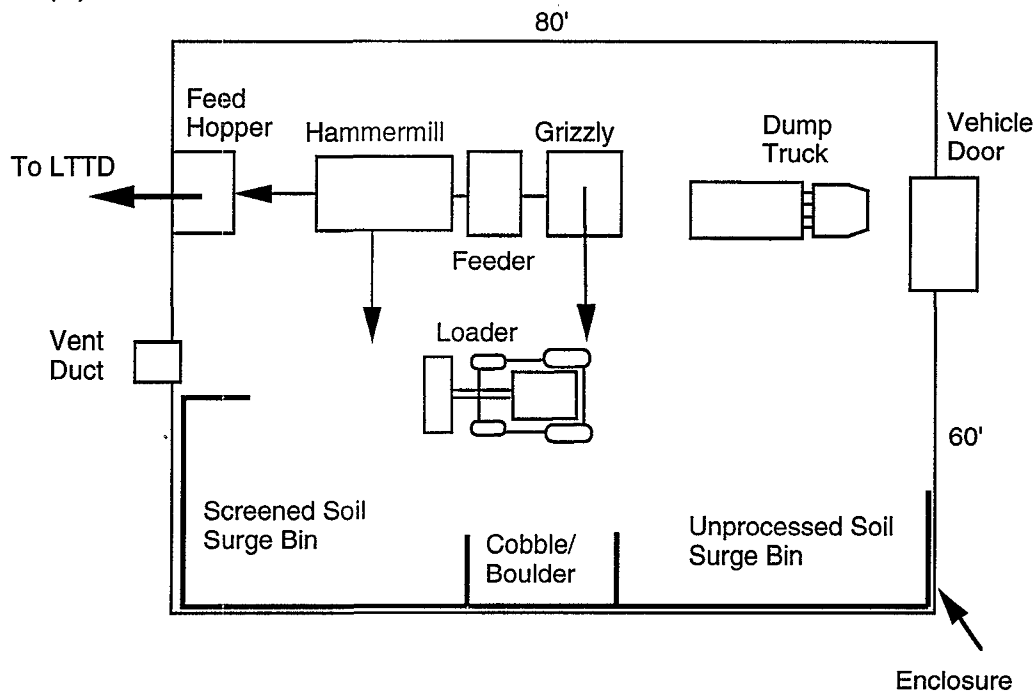
Large boulders and cobbles will be removed from the contaminated soils prior to LTTD treatment or shipping soils to an off-site incinerator. The LTTD unit also requires additional soil pretreatment to achieve a maximum particle size diameter of approximately one inch. Screening and crushing soil will expose fresh surface area and provide mechanical heat input. This vigorous handling will generate greater emissions than excavation. Unlike excavation, soil processing equipment and soil stockpiles will be centrally located. Accordingly, soil pretreatment operations are a good candidate for an enclosure. The enclosure size and equipment layouts for soil pretreatment system are illustrated on Figure C-2. Actual equipment and enclosure size will be determined during the remedial design phase.

For the off-site incineration alternative, excavated material will be placed on a stockpile within the pretreatment enclosure and boulders will be separated using a grizzly screen. Boulders and cobbles greater than 6 inches in diameter will be removed and the remaining soil will be loaded in roll-off boxes and transported to the rail siding. Boulders and cobbles will be placed back in the excavation pit before backfilling.

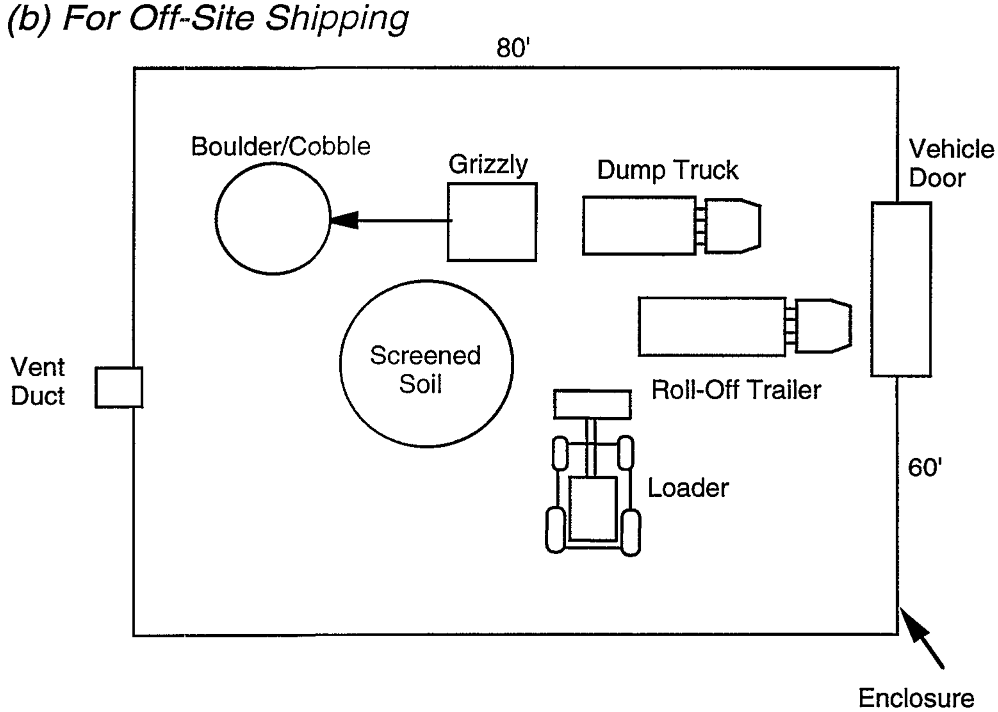
For the LTTD alternative, the material passing through a 6 inch opening grizzly screen will be crushed in a hammermill to achieve the required maximum particle size. To minimize handling steps between soil preparation and LTTD feeding, the soil preparation enclosure will be located next to the LTTD unit feed area. An enclosed conveyor will transfer prepared soil from the soil preparation enclosure directly to the LTTD feed hopper. During the day, sufficient quantities of screened soil will be stockpiled within the enclosure to permit continuous feeding of the LTTD unit during night shifts.

Figure C-2
Enclosure for Soil Processing
Tyson's Site
Focused Feasibility Study

(a) For LTTD Treatment



(b) For Off-Site Shipping



3.3 *RATE OF EXCAVATION*

The capacity or production rate of the various steps are as follows:

• Excavation (8-hr day operation)	400 tons/day
• Grizzly screening and loader capacity	400 tons/day
• Size reduction by hammermill (8-hr/day)	200 tons/day
• LTTD treatment (indirect heating, 24-hr/day)	192 tons/day
• Shipping by rail (from Conrail)	200 to 400 tons/day

Based on the various processing and treatment rates listed above, the most appropriate daily rate for the entire operation including excavation is 200 tons/day.

3.4 *OPEN EXCAVATION*

When soil removal is required, open excavation is the approach taken at most remediation sites. Where VOC emissions may be of concern, steps can be taken to minimize the potential for VOC emissions. Under extreme circumstances, more aggressive control measures, such as using an enclosure, may be warranted. Excavation activities were evaluated to maximize productivity while minimizing risk to on-site workers and off-site residents.

Excavating and truck loading of soil exposes fresh surface area and releases soil pore air which contains contaminants. The EPA guidance documents provide an approach for determining conservative emission estimates for theses activities. Independent of this approach, each step was evaluated in detail to allow greater site specific and activity specific parameter adjustment (ERM, 1994b).

Accurate assessment of the VOC emission potential associated with soil excavating and truck loading is difficult. From a simple, qualitative standpoint, site soil characteristics suggest that little VOC emission will occur during excavation. Soil moisture is an important parameter for control of VOC emissions during excavation and soil processing. Moisture must be driven out of the soil matrix before significant VOC removal can be achieved. For the short period of time the soil is exposed in the open, moisture content will remain high. As described in the soil pretreatment section, a significant amount of surface area will be freshly exposed during soil handling. This is not the case with excavation where the soil is scooped up by the bucket leaving large agglomerates of soil intact. The risk assessment found that diffusion emissions predominate over puff emissions (release of pore space gas). Diffusion is hampered by the presence of moisture and is dependent on the distance the VOC vapor must travel to the exposed surface (See FFS Appendix D Recontamination for a more detailed discussion of VOC vapor migration). These factors minimize emissions during the limited amount of handling involved with excavation. In addition, operation of the SVE system for five years immediately prior to the excavation has preferentially removed the most volatile and mobile compounds which further reduces the potential for VOC emissions.

After excavation and loading, several lesser emission sources exist. The next lesser emission source is the open pit itself. Two simple measures could be taken to reduce the potential for open pit emissions: make the pit as small as practical and cover the pit during periods of inactivity. Analysis suggest that as little as 360 ft^2 is an acceptable size excavation area. Additionally, the dump truck could be covered during the short trip from the excavation area to the soil pretreatment enclosure. The time required to make this trip is on the order of 2-5 minutes and does not constitute a major emission potential.

During the open excavation process, monitoring for fugitive VOC emissions will be conducted. Any unexpectedly high emissions can be curtailed by simply stopping excavation and taking steps to minimize the problem based on determining the exact cause of the emission. The risk posed by open excavation is a cumulative effect requiring continued exposure during the entire excavation period. Early and continual ambient air monitoring will provide an on-going analysis of true exposure and steps can be taken if the emissions began to approach unacceptable values.

3.5 ENCLOSED EXCAVATION

Evaluation of the enclosure size options is based on structures designed and built by Sprung Instant Structures, Inc. (Sprung). Sprung's instant structures consist of light-weight aluminum arches and a PCV coated polyester fabric. The structures can be fabricated, dismantled and relocated in the field using a crane and semiskilled laborers, and are available in widths from 30 to 120 feet with no length limitation. The structure is fixed to the ground using cables to connect the ends of the aluminum arches with the ground anchors.

The narrow and irregularly shaped site and uneven topography limit the use of any enclosure at the Tyson's Site. The enclosure will have to be relocated several times to cover the irregular-shaped excavation areas. Even with relocation, the site conditions do not permit complete coverage of the entire excavation area. The coverage provided by the enclosure and the number of relocations required for the entire site are factors which affect the optimum size of the enclosure. Three enclosure sizes have been evaluated to determine the feasibility of enclosed excavation.

3.5.1 *Large Size Enclosure*

Topographic constraints preclude the use of a single, large, standard structure. Consequently, a large size enclosure will require custom design, manufacturing, and construction. The estimated cost of two large size enclosures (upper west, upper east) is about $2.2 million. The costs for the large enclosures are based on square foot unit prices for materials. Approximately $0.4 million is estimated for air pollution control equipment and operation. Thus, the total cost of large enclosures is about $2.6 million.

3.5.2 *Medium Size Enclosure*

The enclosure size selected for this option is 88.6 feet x 130 feet with two flat ends. The ceiling height is 34 feet along the center and 17 feet towards the side, allowing sufficient room for equipment operation. Leaving a small buffer strip along the edges, the realistic excavation surface area within the enclosure is 78 feet by 122 feet. Considering the typical excavation slope of $1/2$ horizontal to 1 vertical, the maximum excavation area at the bottom of the pit is about 68 feet x 112 feet for a depth of 10 feet.

Operations under a medium size enclosure include: excavation, loading and backfilling (Figure C-3). Excavated soils will be loaded directly on a dump truck and hauled to the soil pretreatment enclosure. Backfilling involves end dumping of the clean soil into the pit and compaction of soil with a vibratory roller. The backfill operation will follow the excavation progress leaving a buffer strip between the clean backfilled soil and the contaminated soil.

A medium enclosure will be set up at five different locations, three for the West Lagoon and two for the Upper East Lagoon (see Figure C-4). Relocation of the enclosure will involve:

- Regrade the ground surface for the new location and install ground anchors.
- Remove equipment from the enclosure.

Figure C-3
Site Layout for Excavation Under Medium Enclosure
Tyson's Site
Focused Feasibility Study

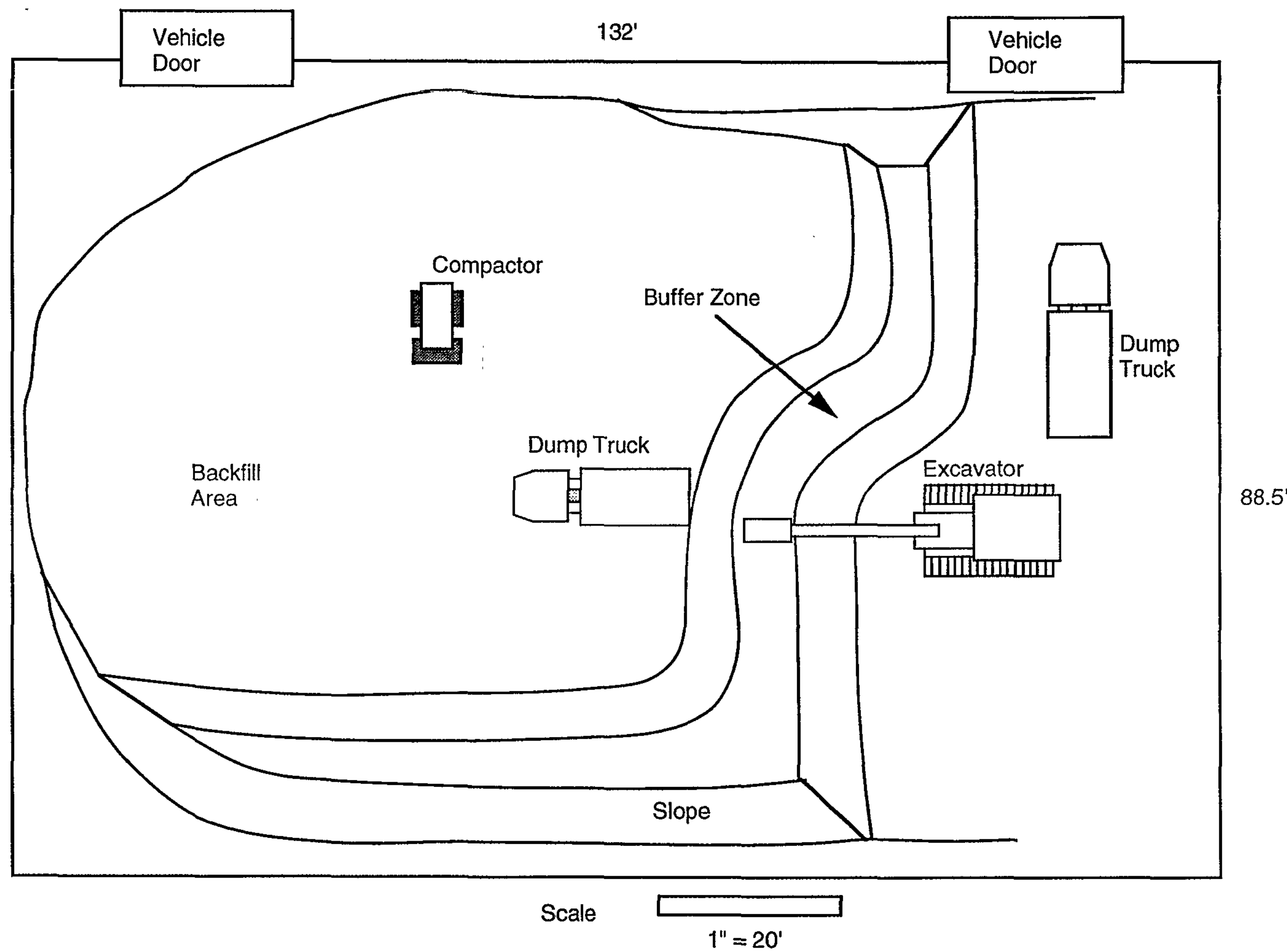
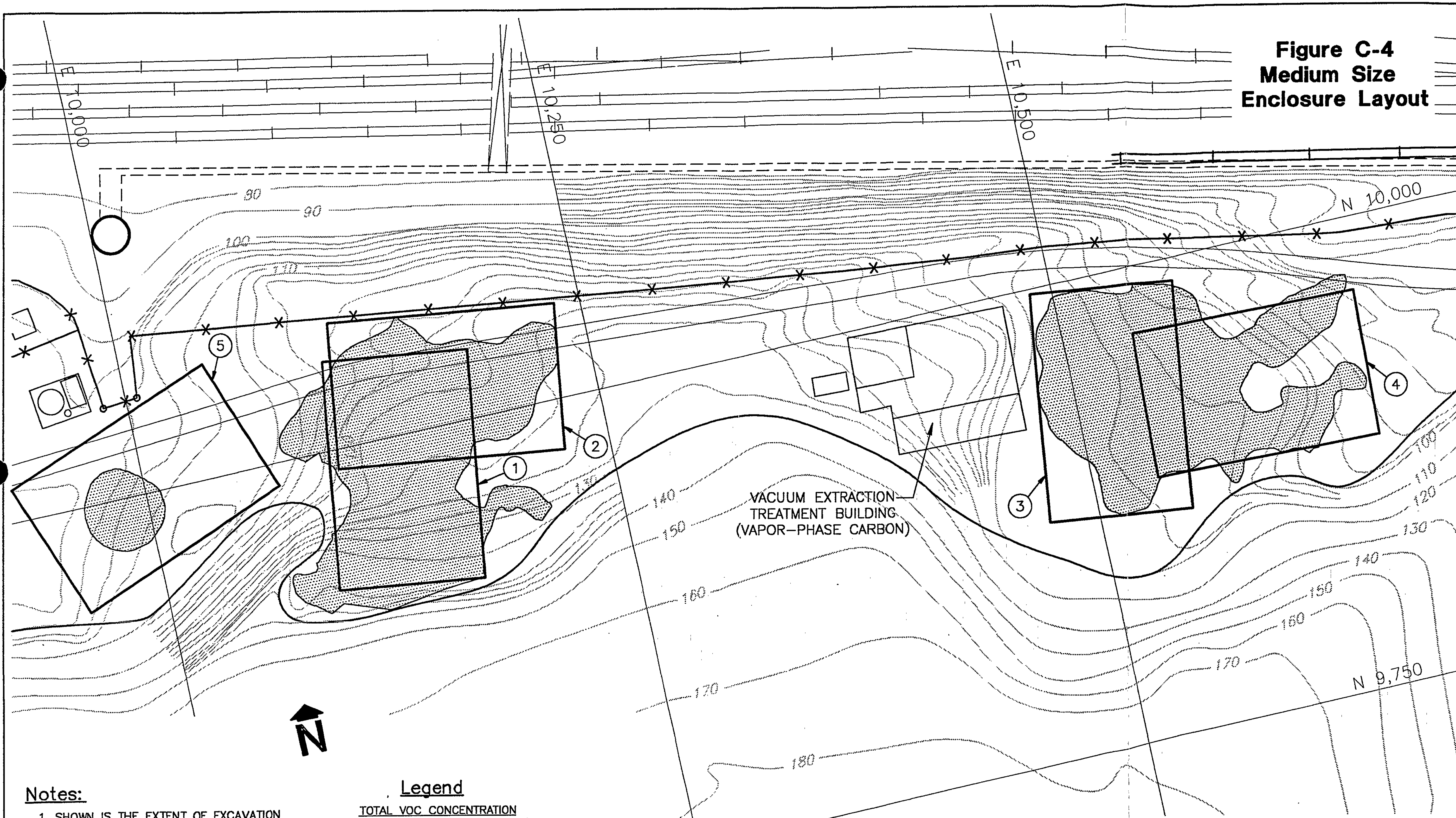


Figure C-4
Medium Size Enclosure Layout



Notes:

1. SHOWN IS THE EXTENT OF EXCAVATION UNDER THE ENCLOSURE. THE FOOTPRINT OF THE ENCLOSURE WILL EXTEND 5 FEET FARTHER OUT IN ALL DIRECTIONS.
2. ENCLOSURE FOOT PRINT = 88.5' x 132'
   EXCAVATION AREA = 78' x 122'
   (UNDER ENCLOSURE)

Legend

TOTAL VOC CONCENTRATION
(AVERAGE THROUGH ENTIRE SOIL COLUMN)

OVER 1,000 ppm

NOTE: TOTAL VOC CONCENTRATIONS FROM TERRA VAC, 1993

50' 25' 0 50' 100'
Scale in Feet

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27222.01.01/07.19.94–TSK/FIG C-4

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- Disconnect and remove the ventilation ducts.
- Cover the exposed excavation face with tarpaulin.
- Disassemble the enclosure into three segments and disconnect from the ground anchors.
- Lift and relocate each segment of the enclosure with a crane.
- Assemble all segments and anchor the frame to the ground.
- Seal the gaps between the ground surface and the enclosure footing with soil.
- Install ventilation ducts.
- Remove the tarpaulin cover from the previous excavation face.
- Move equipment into the enclosure and resume the excavation operation.

Each relocation will take about 12 working days, and requires the following equipment and personnel:

- A crane and operator;
- A crew of 10 laborers;
- A technical consultant to supervise relocation and installation; and
- Support crew to move vent ducts and earthwork equipment.

Unusual installation conditions at the Tyson's Site include moving and erecting the structure over sloping and uneven ground surfaces. To seal the base of the structure to the ground, fabric skirts and extended aluminum frame members will be required in different locations for each setup. These special requirements are expected to increase the time required for each enclosure relocation such that the overall remediation schedule is estimated to be extended by 60 working days. While Sprung structures have been used on numerous level and wide open sites, referenced applications from Sprung do not include installation and relocation on uneven terrain and in restricted conditions similar to those at the Tyson's Site.

The shape of the lagoon area, topographic constraints, and rigid nature of the enclosure structure prevent excavation under the enclosure for some areas along the south high wall. The estimated area of open excavation is 2,900 sq. ft. The volume of soil excavated outside the enclosure is estimated to be 470 cu. yd. These values represent 10% of the total area and 6% of the total volume to be excavated.

Enclosed excavation involves elevated levels of worker safety hazards as follows:

- Working within an enclosed space limits equipment and personnel mobility, creating a higher risk of accident and injury;
- The enclosure will trap the heat generated by solar radiation and equipment working within the enclosure, exposing workers to high temperatures while wearing PPE and causing heat stress.

The estimated cost of enclosures for the medium size option (purchase, installation, relocation) is about $0.8 million. The estimated cost of air pollution control equipment and operation is about $0.3 million. The cost associated with the LTTD standby time and extended site management is estimated to be about $0.2 million. Thus, the total incremental cost of the enclosure is about $1.3 million for a medium size enclosure.

3.5.3 *Small Size Enclosure*

A small enclosure was evaluated to determine the potential for reducing VOC emissions by providing more complete coverage of the excavation area, especially along the high wall. The estimated area of open excavation is 1,600 sq. ft. The enclosure size for this option is 60' x 80' with two flat ends as shown on Figure C-5. The ceiling height is 25 feet along the peak and 12 feet along the sides, allowing adequate room for equipment operation. The time to excavate the volume of soils that can be contained within the enclosure (three to six days) is less than the time necessary to move the enclosure (six days). Consequently, a second enclosure will be required to allow excavation under one while the other is being moved. Using two enclosures for excavation will minimize potential schedule delays. However, one enclosure will have to be assigned to the West Lagoon and the other to the East Lagoon as two enclosures within one lagoon would interfere with haul truck movement, and crane operation. A dedicated crane will be provided to accommodate the frequent enclosure movements.

Operations under a small size enclosure are the same as under a medium size enclosure, except that backfilling is accomplished after the enclosure is moved to the next location. When the maximum extent of excavation is reached, the excavation pit will be covered with a few feet of backfill soil and the enclosure will be moved to a new location. Backfilling will be completed outside the enclosure and the excavation operation will be repeated at the new location.

Figure C- 6 depicts the site layouts and progressive excavation with enclosure relocation. The enclosure will be set up at 18 different locations,

Figure C-5
Site Layout for Excavation under Small Enclosure
Tyson's Site
Focused Feasibility Study

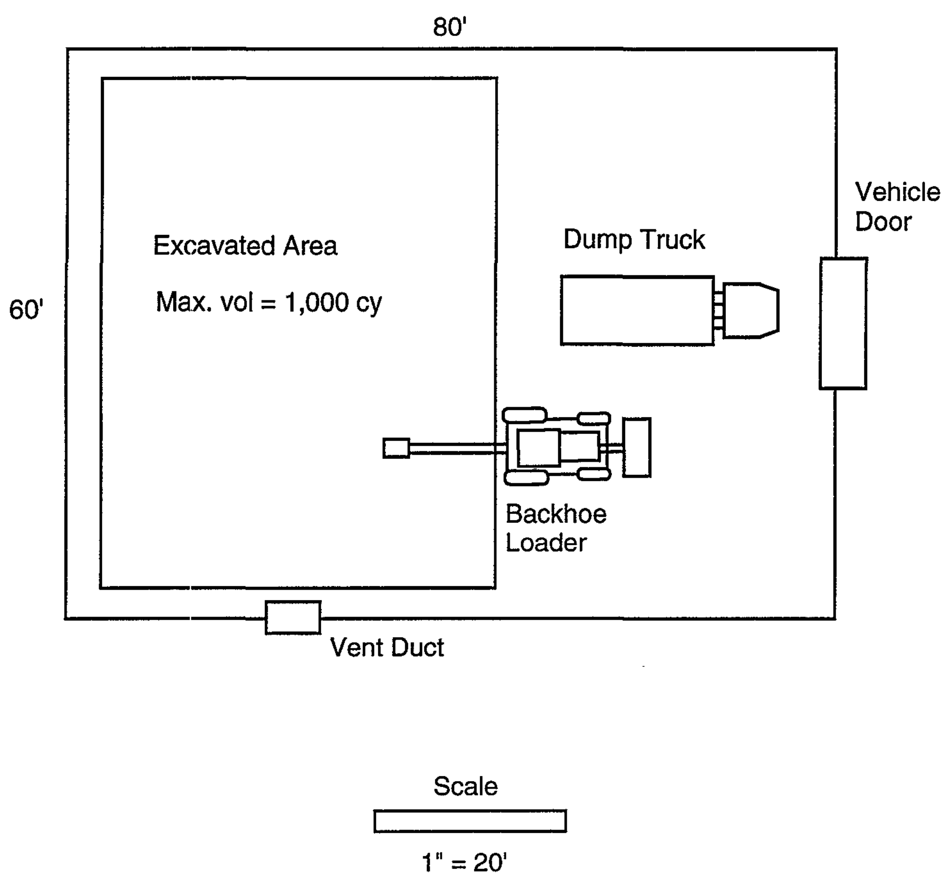
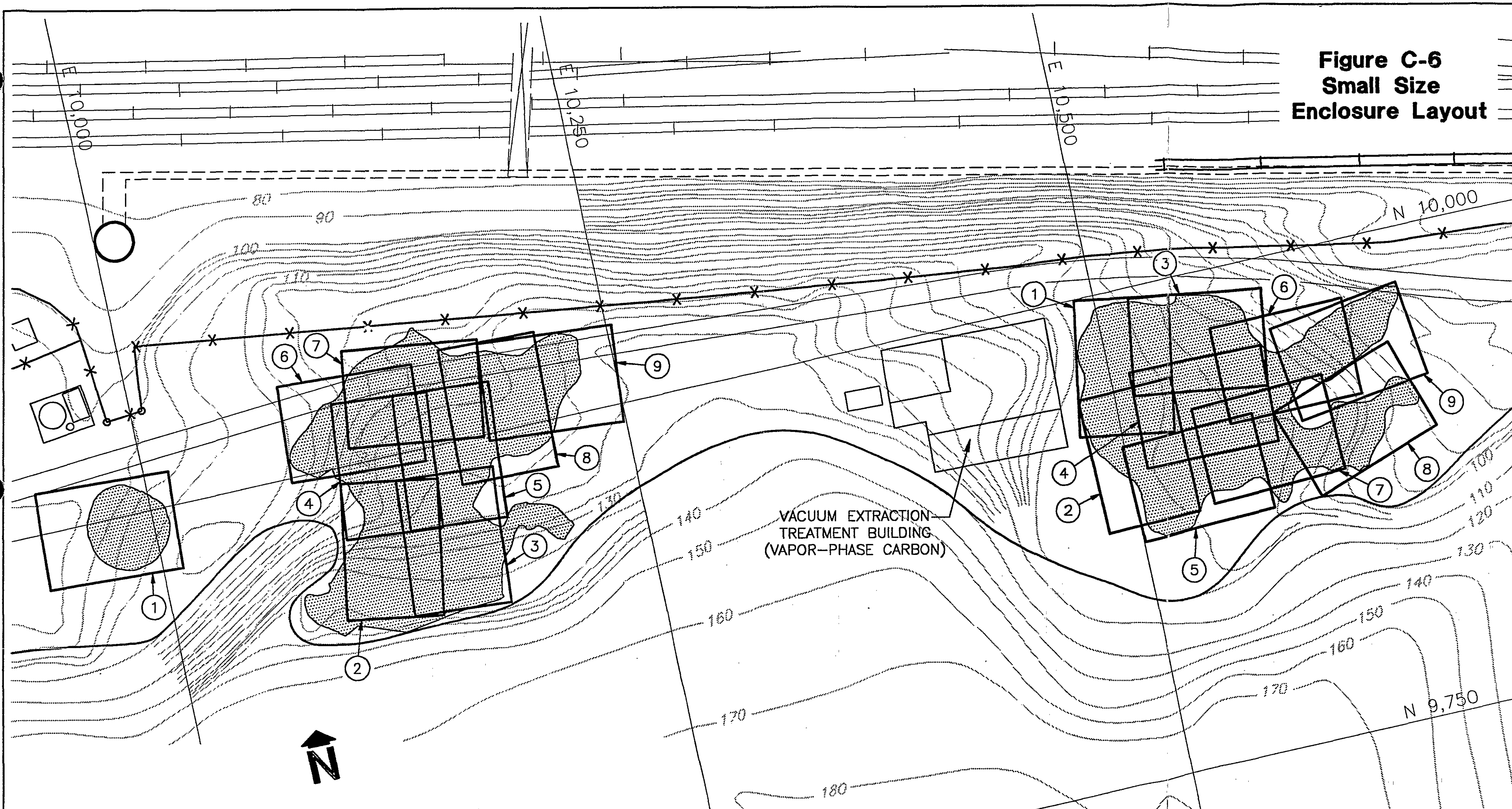


Figure C-6
Small Size
Enclosure Layout



Notes:

1. SHOWN IS THE EXTENT OF EXCAVATION UNDER THE ENCLOSURE. THE FOOTPRINT OF THE ENCLOSURE WILL EXTEND 5 FEET FARTHER OUT IN ALL DIRECTIONS.
2. ENCLOSURE FOOT PRINT = 60' x 80'
   EXCAVATION AREA (UNDER ENCLOSURE) = 50' x 70'

Legend

TOTAL VOC CONCENTRATION
(AVERAGE THROUGH ENTIRE SOIL COLUMN)

OVER 1,000 ppm

NOTE: TOTAL VOC CONCENTRATIONS FROM TERRA VAC, 1993

50' 25' 0 50' 100'
Scale In Feet

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27232.04.01/07.19.94–TSK/FIG C–6

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and relocation will involve the steps described in Section 2.3 for the medium size enclosure. The small size enclosure will be disassembled into two pieces for relocation (as compared to three pieces for the medium size enclosure). Each relocation is expected to take about 6 working days, including new site preparation and air duct installation, and require the following equipment and personnel

- A crane and operator;
- A crew of 8 laborers;
- A technical consultant to supervise relocation and installation; and
- Support crews to move vent ducts and earthwork equipment.

As shown in Figure C-6, some areas along the south high wall have to be excavated outside the enclosure. The estimated area of open excavation is 1,600 sq. ft. The volume of soil excavated outside the enclosure is estimated to be 240 cu. yd. These values represent 6% of the total area and 3% of the total volume to be excavated. The volume of open excavation outside the enclosure is about half of that necessary for the medium enclosure. However, nearly six times as many enclosure relocations will be needed. Since the open excavation volume difference is only three percent of the total excavation volume, there is little added benefit in comparison to the added number of enclosure relocations.

The estimated cost of enclosures for the small enclosures option (purchase, installation, relocation) is about $1.0 million. The estimated cost of air pollution control is about $0.2 million. There is no added cost associated with the LTTD standby time as the two enclosures allow continuous excavation. Thus, the total incremental cost of the enclosure for soil excavation and treatment is about $1.2 million for small size enclosures.

3.6 *AIR HANDLING REQUIREMENTS*

Equipment operators within the enclosure will work in a sealed cabin with positive air supply. Other workers within the enclosure will work at a minimum in level B protection. Even though the workers will be protected by personal protective equipment (PPE), the vapor concentrations within the enclosure should not exceed a specified action level to protect the workers in case of PPE malfunction and accidental loss of protection effectiveness.

To maintain vapor concentrations below a specific action level, air within the enclosure will be drawn out using centrifugal blowers and treated using vapor-phase carbon beds. The air exchange ratio will depend on the vapor emission rate and the enclosure size. Since a slightly negative pressure (i.e., slightly lower than the atmospheric pressure) will be maintained within the enclosure, VOC emissions through the membrane and minor defects will be minimal. The actual size of the air handling system will be based on estimated or measured (from pilot-scale tests) emission rates and the selected enclosure size.

4.0 SUMMARY AND RECOMMENDATION

4.1 SOIL REMOVAL VOLUME

Excavation of highly contaminated lagoon area soils (> 1,000 mg/Kg VOC) will remove more than 99% of the VOC mass in the unsaturated zone soil; however, VOC emissions after backfilling of clean soils will still be 40% of the pre-excavation levels. If treatment or disposal of lagoon area soils is required, excavation of soils with total average VOC concentrations less than 1,000 mg/kg is not justified because of the insignificant reduction in VOC flux and contaminant mass.

4.2 EXCAVATION APPROACH

Operational, safety and cost effectiveness issues make excavation under an enclosure less implementable. Specifically the following factors complicate the implementation of this emission control technique.

- Excavation worker safety, in an enclosure, is a significant concern because of potential hazards including heat, mechanical injury and chemical exposure.
- Custom engineered and designed enclosure structures may be required depending on optimal design considerations.
- The overall remediation schedule will be extended to accommodate installation and relocation of enclosures.
- The uneven topography of the site will complicate placement, sealing and movement of the enclosure.
- Cost and schedule increases are significant.

This evaluation concludes that excavation of lagoon area soils, if required, should be conducted as follows:

- Proceed in small open excavation areas;
- Cover-exposed subsurface and stockpiled soils during non-operational periods;
- Cover vehicles for on-site transportation;
- Limit direct contact exposure to soils; and

- Provide for minimal disturbance of excavated materials, so as to reduce potential fugitive emissions.

VOC emissions will be continually monitored with appropriate action taken, if required. In addition, a fixed enclosure for soil preprocessing prior to on-site treatment or loading for off-site disposal is appropriate because of the potential to capture the most significant fugitive emissions source and the relative ease of implementation. Excavation under an enclosure is not warranted because the incremental risk reduction for off-site receptors is small, and the potential benefit is largely offset by increased exposure risks and safety concerns for remediation workers, technical implementation difficulties and an extended schedule.

REFERENCES

ERM, 1989, "Results of Initial Soil Sampling Episode and Sampling Plan for the Interim Episode for the Vacuum Extraction Remedy", August 1989.

ERM, 1994a, Internal Memorandum from S. Fulton/S. Schory to Tyson's FFS File, 19 May, 1994.

ERM, 1994b, "VOC Emissions from Open Excavation and Enclosed Soil Screening", August 1994.

TerraVac, 1994 "Site Characterization Report", June 1994.

Appendix D
Evaluation of Contamination of Replaced Soils Following Excavation as a Result of Vapor Migration

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EVALUATION OF CONTAMINATION OF BACKFILLED SOILS FOLLOWING EXCAVATION AS A RESULT OF VAPOR MIGRATION

TYSON'S SITE, MONTGOMERY COUNTY PENNSYLVANIA

Final Report

September 22, 1994

Prepared by:

Stanley Feenstra, M.Sc., CGWP

Prepared for:

Ciba Corporation

Toms River, New Jersey

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1. Introduction

Two of the remedial alternatives considered for the Tyson's Site include the excavation of contaminated soils from the unsaturated zone of the former disposal lagoons. Following excavation of the soils, there will remain a substantial quantity of chemical contaminants, including DNAPL (dense non-aqueous phase liquids) in the underlying soils and bedrock below the water table beneath the former lagoons.

The principal contaminants in the former lagoon area soils are volatile organic chemicals (VOCs) such as 1,2,3-trichloropropane (TCP) and xylene. In the event of any lowering of the water table, portions of the remaining contaminated soil and bedrock will be exposed. The contaminated soil and DNAPL will release vapors to the pore air in the unsaturated zone. If the unsaturated soils are excavated and replaced with clean fill, there is a significant potential for VOC vapors to migrate upward into the clean fill. Fluctuations in the water table will also carry contaminants upward into the overlying unsaturated materials. The upward migration of vapors will result in the contamination of the previously clean fill up toward the ground surface. Upward migration will occur as a result of diffusion of vapors and as a result of displacement of vapors upward during times when the water table rises. The possibility of upward diffusion of vapors and the recontamination of the replaced soils were first assessed by Stan Feenstra in the report: "Evaluation of Contamination of Replaced Soils following Excavation of the Lagoon Area, Tyson's Site" dated April 23, 1987.

This report describes a further evaluation of the contamination of the replaced soils following excavation of the lagoon area soils at the Tyson's Site. Since the first evaluation in 1987, there have been advances in the understanding of organic vapor migration in the subsurface as a result of laboratory experiments, controlled field experiments and computer modeling. These advances have supported the initial conceptual model that vapor migration is an important process in the redistribution of contaminants in the unsaturated zone. The present evaluation will involve simulations of vapor transport upward through the clean fill, and calculations to determine the degree of soil contamination that might be expected as a result of the vapor transport.

2. Concepts for Vapor Migration

2.1 Background

The evaluation of vapor migration performed for the Tyson's site in 1987 was based on the fundamental principles of organic chemical partitioning in soils and a diffusive transport model developed originally for the migration of radioactive gases from an underground radioactive waste repository. Since 1987, there have been considerable advances in the understanding of the migration of organic chemical vapors in the unsaturated zone. These advances have resulted from computer modeling of the fundamental transport phenomena, comparison of the models to laboratory experiments, comparison of the models to controlled field experiments, and detailed field studies. These advances have confirmed that the diffusion of organic vapors is an important process for the transport of vocs in the unsaturated zone, and can result in upward, downward and lateral vapor migration in the unsaturated zone.

2.2 Vapor Migration from Contaminated Groundwater

Studies of voc vapors in soil gas at industrial and waste disposal sites began in the early 1980s with attempts to use soil gas surveys to delineate dissolved contaminant plumes in groundwater and zones of soil contamination in the unsaturated zone (Lapella and Thompson, 1983; Marrin and Thompson, 1984; Marrin and Thompson, 1987; Devitt et al., 1987). Successful use of this technique for delineation of groundwater plumes relies on the transfer of vocs from the shallow groundwater to the vapor phase in the unsaturated zone with subsequent diffusion of vapors up toward the ground surface. The lateral extent of the measured voc concentrations in the soil gas is considered to reflect the lateral extent of the groundwater plume. Although the use of soil gas surveys has been relatively successful in site investigations, it has been recognized that care is required in interpretation of the results of soil gas surveys because of the potential complexity of vapor transport processes (Marrin, 1988). Most recently, laboratory studies (McCarthy and Johnson, 1993; Cho et al. 1993) suggest that the rate of transfer of VOCs from the groundwater zone to the unsaturated zone may be relatively low and controlled by aqueous-phase diffusion through the capillary fringe and upper groundwater zone. Fluctuations in the elevation of the water table will likely enhance transfer of VOCs to the unsaturated zone.

Vapor diffusion upward from contaminated groundwater has been demonstrated in field experiments and detailed site studies. Figure 1 shows a vertical profile of TCE (trichloroethylene) concentrations measured in soil gas and groundwater from a groundwater plume present at the water table in a sandy aquifer (Rivett, 1993). The contamination originated from a source of TCE liquid (DNAPL) that was placed in the unsaturated zone as part of a controlled field experiment (Hughes et al., 1992) about 70 m upgradient of the location of this profile. Data collected as part of that experiment suggested that soil-gas contamination at this location was not influenced by lateral migration of vapors from the DNAPL source. Therefore, the soil-gas profile shown in Figure 1 was interpreted to be due to upward diffusion from the dissolved-phase contaminant plume which had migrated laterally in the capillary fringe and shallow groundwater from the DNAPL source area.

At the Figure 1 location, the groundwater plume would have been present for only 3 to 6 months. Detectable (>0.001 μg/L) soil-gas concentrations were observed from the water table up to the ground surface over a distance of 5 m. TCE concentrations decline exponentially, suggesting that the diffusion profile had not reached steady state.

A similar example of upward migration of TCE vapor from a groundwater plume in a sandy aquifer, as reported by Smith et al. (1990), is shown in Figure 2. The location of this profile is about 300 m from the source of the contamination, a wastewater disposal lagoon. Smith et al. consider that this location has not been influenced by lateral vapor transport from the source area. At this location, the ground-water plume has likely been present for about 20 years. Detectable (>0.04 μg/L) TCE concentrations were observed in soil gas from the water table to the ground surface over a distance of about 3 m. The TCE concentrations decline linearly, suggesting a steady-state diffusion profile. Soil concentrations were not measured at this location but TCE concentrations measured in soil in nearby borings ranged from 5,000 to 8,000 μg/kg.

2.3 Vapor Migration from DNAPL Zones

Studies of VOC vapor transport related specifically to vapor migration from DNAPL sources began in 1980s when it was recognized that DNAPL occurred in the subsurface at many industrial facilities and waste disposal sites, and that it may be an important factor in the spread of contaminants at these sites (Feenstra and Cherry, 1988; Mercer and Cohen, 1990). Interpretation of site conditions and consideration of possible transport scenarios have been aided by the development of numerical vapor-transport models which incorporate many of the relevant physical and chemical processes related to vapor migration from a DNAPL source.

Baehr (1987) developed one of the first computer models to assess the migration of organic vapors in the unsaturated zone with specific regard to the groundwater contamination and soil contamination that would result from that migration. Baehr developed both analytical and numerical solutions for vapor transport and concluded that the physical and chemical properties of the organic chemical and the degree of partitioning between the soil air, soil water and soil solids will control the rate and extent of vapor migration. Simulations performed for a sandy soil (porosity = 0.4 and water content = 0.1) indicated that xylenes could migrate distances of 1 m to 2 m upward to the ground surface and outward from a source zone in as little as 10 days.

Sleep and Sykes (1989) developed a more rigorous numerical model which could account for the infiltration of precipitation into the unsaturated zone and variable water saturations. Simulations of TCE (trichloroethylene) in a sandy unsaturated zone indicated that TCE migrated 1 m upward to the ground surface and 10 m to 15 m outward from a source zone in about 1 year.

Falta et al. (1989) developed a numerical model that could account for density-induced advection in addition to diffusion. Simulations of carbon tetrachloride in a relatively fine-grained unsaturated zone (porosity = 0.4, water saturation = 0.25) indicated that carbon tetrachloride migrated 5 m upward to the ground surface and 10 m to 15 m outward from a source zone after about 1 year.

Jury et al. (1990) developed an analytical screening model to estimate the magnitude of vapor losses from contaminated soil in the subsurface. Simulations were performed to consider migration of a wide range of volatile organic chemicals through a 1 m soil cover overlying contaminated soil containing about 15 mg/kg of the various chemicals. Both a sandy and clayey soil cover were considered. The simulation showed that virtually all of the chemicals exhibited transport through the soil cover to the ground surface after 1 year.

Some of the best illustrations of vapor transport processes come from research performed by the Waterloo Centre for Groundwater Research and the Oregon Graduate Institute. A numerical computer model was developed by Mendoza and Frind (1990a,b) which could account for all the relevant physical and chemical processes. Simulations from the model were compared to laboratory experiments of vapor migration conducted in a 10 m by 10 m by 3 m test cell (Johnson et al., 1992) and a controlled field experiment (Hughes et al., 1992; Mendoza et al., 1992). The laboratory experiment performed in coarse sand indicated the migration of 1,1,1-trichloroethane (TCA) outward 6 m to 8 m from a source zone in 14 days. The field experiment performed in medium sand indicated TCE migration about 7 m to 8 m outward from a source zone in 18 days. In both the laboratory and field cases, the model simulations of vapor migration compared extremely well with the observed rate and extent of vapor migration.

The research described above clearly illustrate, that the migration of organic vapors in the unsaturated zone is a real and important process in situations where volatile organic chemicals are present in the unsaturated zone. The partitioning of vapors into the soil water and soil solids will occur as vapors migrate through the unsaturated zone and soil contamination will result from vapor migration into previously uncontaminated areas. Vapor migration will expand the size of the zone of soil contamination within the vadose zone.

3. Tyson's Site

3.1 Concept for Vapor Migration through Replaced Soil

Following excavation of the contaminated soils above the saturated zone at Tyson's site, DNAPL-impacted soil and bedrock will remain in the saturated zone beneath the former lagoons. As a result of fluctuations in the elevation of the water table (assumed to be 2 to 4 feet), some portion of these DNAPL-impacted zones will be exposed periodically in the unsaturated zone. The DNAPL-impacted soil and bedrock located within the zone of water table fluctuation will release vapors to the pore air. As the contaminants of concern are gradually released into the pore air and contaminant vapors are formed in the former portion of the unsaturated zone, upward migration of vapors will occur as a result of diffusion and will contaminate the clean fill.

The principal compounds of concern are 1,2,3-trichloropropane, xylenes, ethyl benzene, toluene, perchloroethylene (PCE) and trichloroethylene (TCE). Only TCP and xylene are considered further in this evaluation. On the basis of their physical and chemical properties, xylene, toluene, PCE and TCE vapor will exhibit comparable mobility. Xylene was selected to represent this group of compounds because it occurs at the highest concentrations in the lagoon area soils. TCP and ethyl benzene vapor will be considerably less mobile. TCP was selected to represent this latter group of compounds because it occurs at the highest concentrations in the lagoon-area soil and has a potenial to pose the most significant health risk.

3.2 Application of Vapor Diffusion Model

The nature and rate of upward vapor diffusion can be examined using a one-dimension analytical solution developed by Green and Evans (1985). This solution considers migration through a soil column of finite length from a source of constant vapor concentration to the atmosphere where the vapor concentration is 0. This solution is given by:

$$\frac{C_a(z,t)}{C_{ao}} = \frac{2}{\pi}\sum_{i=1}^{\infty} \sin\left(\frac{i\pi z}{L}\right)\frac{1}{i}\left\{1-\exp\left(\frac{D_{er} i^2 \pi^2 t}{\theta_a L^2}\right)\right\}$$

where:

$C_a(z,t)$	is the vapor concentration at distance z, from the source at time t.
C_{ao}	is the vapor concentration at the source.
$\frac{C_a(z,t)}{C_{ao}}$	is the relative vapor concentration.
D_{er}	is the reactive effective diffusion coefficient.
θ_a	is the air-filled porosity.
L	is the length of the soil column.

The effective diffusion coefficient for vapors through partially water-saturated soils can be described empirically by:

$$D_e = D_a \frac{\theta_a^{10/3}}{\theta_t^2}$$

For vapors which will dissolve in the soil water and sorb on soil solids, a reactive effective diffusion coefficient can be defined by:

$$D_{er} = \frac{D_a \ \theta_a^{10/3}}{\theta_t^2 \ R_v}$$

where:

D_a	is the free-air diffusion coefficient.
R_v	is the vapor retardation factor.

θ_a	is the air-filled porosity.
θ_t	is the total porosity.

The retardation of organic chemical vapors in soil due to sorption on soil solids has not been extensively studied. However, recent laboratory experiments by Chiou and Shoup (1985) suggest that the mechanisms for sorption of organic vapors in partially water saturated soils are comparable to those for the sorption of dissolved organics in water saturated soils. Baehr (1987) defined the vapor retardation factor as:

$$R_v = 1 + \frac{1}{H}\frac{\rho_b K_d + \theta_w}{\theta_a}$$

where:

R_v	is the vapor retardation factor
H	is the dimensionless Henry's Law Constant
θ_a	is the air-filled porosity.
θ_w	is the water-filled porosity.
ρ_b	is the dry bulk density of the soil
K_d	is the distribution coefficient

The sorption of dissolved organic chemicals on soils has been extensively studied and is described by the distribution coefficient. A high K_d value indicates a high degree of sorption. In most situations the K_d for organic chemicals is determined by the organic carbon content of the soil (f_{oc}) and the degree of partitioning of the chemicals on the soil organic matter as expressed by an organic carbon partition coefficient (K_{oc}).

$$K_d = K_{oc} f_{oc}$$

The organic carbon partition coefficient for various chemicals on various soils can be determined in the laboratory or can be estimated based on the octanol-water partition coefficient or water solubility of the chemical.

A listing of the chemical properties of the principal vocs found in the lagoon-area soil at the Tyson's Site is shown in Table 1. For the Tyson's Site, it is assumed that the backfilled soils would be of a relatively sandy nature having a porosity of 0.4, a water content of 0.15, and an organic carbon content of 1.0 %. A listing of the calculated vapor retardation factors and air-phase diffusion coefficients is shown in Table 2.

Table 1. Chemical properties of the principal vocs found in the lagoon-area soils at Tyson's.

Compound	MW (g/mol)	VP (mm Hg)	C_a^S (mg/L)	C_w^S (mg/L)	H (unitless)	K_{oc} (cm^3/g)
1,2,3-TCP	147.4	3	24	1,900	0.0167	72
Xylenes	106.2	8	46	200	0.288	240
Ethylbenzene	106.2	10	57	135	0.263	1,100
Toluene	92.1	30	149	580	0.261	300
PCE	165.8	19	170	240	0.753	363
TCE	131.4	75	531	1,380	0.421	104
Benzene	78	95	399	1,780	0.227	49

MW	molecular mass
VP	vapor pressure
C_a^S	saturated air concentration
C_w^S	solubility in water
H	Henry's Constant
K_{oc}	organic carbon - water partition coefficient

Table 2. Calculated vapor diffusion coefficients for vocs through the backfilled soil. Based on a total porosity of 0.4, an air-filled porosity of 0.25, a bulk dry density of 1.6 g/cm^3, and an organic carbon content of 1.0 wt.%.

Compound	D_a (m^2/s)	R_v	D_e (m^2/s)	D_{er} (m^2/s)
1,2,3-TCP	7.30E-06	308	1.80E-06	5.85E-09
Xylenes	7.30E-06	56	1.80E-06	3.20E-08
Ethylbenzene	7.60E-06	270	1.88E-06	6.96E-09
Toluene	8.10E-06	77	2.00E-06	2.59E-08
PCE	7.60E-06	33	1.88E-06	5.75E-08
TCE	8.40E-06	18	2.08E-06	1.15E-07
Benzene	9.00E-06	18	2.10E-06	1.20E-07

D_a is the free-air diffusion coefficient

R_v is the vapor retardation factor

D_e is the non-reactive diffusion coefficient

D_{er} is the reactive diffusion coefficient

The one-dimensional analytical solution described in the preceding paragraphs was used to simulate the upward migration of organic vapors from the underlying saturated zone into the backfilled soils which will be placed in the excavation following removal of the contaminated soils from the unsaturated zone.

For the case at the Tyson's Site, soil column lengths (L) of 6.5 ft. (2 m) and 13.1 ft. (4 m) were used to represent the possible range in the thickness of replaced soils for the area of the former lagoons.

Using these values for the effective diffusion coefficients and soil column lengths of 6.5 ft. (2 m) and 13.1 ft. (4 m) , vapor transport upward through the replaced soils was examined using the one-dimensional analytical solution shown in the preceding discussion. Relative vapor concentrations were determined at 0.33 to 0.67 ft. (0.1 to 0.2 m) intervals up from the bedrock to the ground surface at times ranging from 0.1 years to 10 years following replacement of the soils. The solution was evaluated using Excel 4.0 spreadsheet software on an Apple Macintosh microcomputer. The infinite *sin* series does not converge to a solution rapidly. As many as 250 iterations were required to provide a satisfactory solution.

The model assumes that the movement of soil water is negligible with respect to the rate of vapor transport. The infiltration of water downward through the unsaturated zone will tend to inhibit the upward diffusion when the rate of upward vapor migration is low relative to the rate of downward flow of water. This will occur when vapor migration is reduced by high water-filled porosity, or when the rate of downward water flow is very low. However, for the model simulations shown here for a water-filled porosity of 0.15 (water saturation 37.5% of total porosity), the rate of upward vapor migration through the replaced soils at Tyson's Site will be rapid relative to the expected rate of water movement through the unsaturated zone.

3.3 Model Simulation Results

The results of the model simulations are shown for TCP in Figures 3 and 4, and for xylene in Figures 5 and 6. The rate of migration of TCP vapor is considerably slower than that of xylene vapor due to the effects of partitioning into the soil water. For the 6.5 ft. (2 m) soil column, after 1 year, TCP relative vapor concentrations are approximately 0.50 at a depth of 5.0 ft. (1.5 m) and 0.1 at a depth of 3.0 ft. (0.9 m). After 4 years, TCP relative vapor concentrations are approximately 0.50 at a depth of

4.0 ft. (1.2 m) and 0.1 at a depth of 1.0 ft. (0.3 m). The vapor concentration profile at 4 years represents near steady-state conditions when there exists a uniform concentration gradient between the underlying contaminated zone and the ground surface.

Vapor concentration profiles for xylene are similar in form but are established more rapidly because of the lower degree of partitioning into the soil water for xylene. For the 6.5 ft. (2 m) soil column, after 0.1 years, xylene relative vapor concentrations are approximately 0.50 at a depth of 5.5 ft. (1.7 m) and 0.1 at a depth of 4.0 ft. (1.2 m). After 1 year, xylene relative vapor concentrations are approximately 0.50 at a depth of 3.5 ft. (1.1 m) and 0.1 at a depth of less than 0.8 ft. (0.24 m). The vapor concentration profile at 1 year represent near steady-state conditions when there exists a uniform gradient between the bedrock and the ground surface.

Vapor concentration profiles for the 13.1 ft. (4 m) soil column are similar to those of the 6.5 ft. (2 m) soil column but are established more slowly. Steady-state uniform gradients for TCP and xylene develop in about 10 and 3 years respectively compared to about 4 years and 1 year required for the thinner soil column.

4. Chemical Concentrations on Backfilled Soils

4.1 Calculation of Soil Concentrations

The vapor migration simulations described in the preceding section provided estimates of the relative TCP and xylene vapor concentrations that could develop in the backfilled soils above the water table. As a result of dissolution of the VOC vapor into the soil water, and sorption of VOCs onto the soil solids, the upward diffusion of vapors will result in contamination of the backfilled soil in the unsaturated zone.

The concentrations of TCP and xylene in the backfilled soils that result from the upward vapor migration can be calculated based on the vapor concentrations, the organic carbon content of the soil, and the Henry's Law Constants of the two chemicals. This relationship is modified from Feenstra et al. (1991) and is described by:

$$C_t = C_a\left[\frac{\left(K_d\rho_b + \theta_w\right) + H\theta_a}{H\ \rho_b}\right]$$

where:

C_t	is the total soil concentration
C_a	is the concentration in the soil air
H	is the dimensionless Henry's Law Constant
θ_a	is the air-filled porosity.
θ_w	is the water-filled porosity.
ρ_b	is the dry bulk density of the soil
K_d	is the partition coefficient for the backfilled soil

For the purpose of this report, the bulk chemical concentrations in the backfilled soil will be considered to be that dissolved in the soil water plus that sorbed to the solids. This would represent the concentration which would be determined by laboratory chemical analysis of a soil sample extracted with methanol. As for the vapor migration simulations, it is assumed that the backfilled soils have a porosity of 0.4, a water content of 0.15, and an organic carbon content of 1.0 %.

The calculation of the VOC concentrations in the backfilled soil also requires estimates of the VOC concentrations in the soil air at the bottom of the unsaturated zone. For the purpose of this report, calculations will be performed using estimates of the vapor concentrations in areas where DNAPL is present and areas where DNAPL is absent. This is comparable to the evaluation of upward vapor flux from the lagoon area soils performed in the Exposure Assessment Memorandum prepared by ENVIRON Corporation dated July 1994.

4.2 DNAPL-Containing Areas

In areas where DNAPL is present, the VOC vapor concentrations in the soil air is determined by the chemical composition of the DNAPL and the pure-phase vapor pressures of the constituent compounds. The VOC concentration for each compound in air can be estimated by:

$$C_a = MF\ C_a^s$$

$$C_a^s = \frac{VP}{P_s}\frac{MW}{V_m}$$

where:

C_a	is the concentration in the soil air
C_a^s	is the saturated pure-phase vapor concentration

MF	is the mole fraction of the compound in the dnapl
VP	is the pure-phase vapor pressure of the compound
P_s	is standard atmospheric pressure
MW	is the molecular weight of the compound
V_m	is the standard molar volume

Values for the saturated pure-phase vapor concentrations are shown in Table 1.

The DNAPL found in the lagoon area soils and bedrock at the Tyson's Site is a complex mixture of VOCs and non-volatile organic compounds. Although samples of DNAPL recovered from the lagoon area soils have not been analysed, the composition of the DNAPL can be estimated based on the results of analyses of soil samples from the deeper portions of the former lagoons. Table 3 shows the relative concentrations of the principal VOCs found at the site based on the average concentrations in soil in DNAPL areas found in Table 7 of the Exposure Assessment Memorandum prepared by ENVIRON. Table 3 also shows the calculated mole fraction concentrations of the principal VOCs for the DNAPL.

Table 3. Estimated composition of DNAPL in lagoon-area soils.

Compound	Measured Relative Conc. (%)	MW (g/mol)	Molar Conc. (mmol/g)	Mole Fraction
1,2,3-TCP	29.1	147.4	1.97	0.23
Xylenes	40.9	106.2	3.85	0.44
Ethylbenzene	13.5	106.2	1.27	0.15
Toluene	12.7	92.1	1.38	0.16
PCE	3.1	165.8	0.19	0.022
TCE	0.4	131.4	0.03	0.0034
Benzene	0.3	78.0	0.04	0.0046

With the saturated pure-phase vapor concentrations shown in Table 1 and the estimated DNAPL mole fractions shown in Table 3, the estimated concentration of TCP and xylene in the soil air in areas containing DNAPL are 5.5 mg/L and 20 mg/L respectively. The estimated soil-air concentrations for the all the principal VOCs are shown in Table 4.

Based on the vapor transport simulations and the vapor concentrations noted above, soil concentration profiles above DNAPL-containing areas were calculated. These profiles are shown for TCP in Figures 7 and 8, and for xylene in Figures 9 and 10. TCP and xylene concentrations in soil close to the water table are about 300 mg/kg and 200 mg/kg respectively.

For the 6.5 ft. (2 m) soil thickness, TCP soil concentrations are about 20 mg/kg at 3 ft. (0.9 m) and about 1.5 mg/kg at 1 ft. (0.3 m) after 1 year. After 4 years, TCP soil concentrations are about 100 mg/kg at 3 ft. (0.9 m) and about 30 mg/kg at 1 ft. (0.3 m). For the greater soil thickness, longer time periods are required to achieve comparable soil concentrations in the upper portions of the replaced soil. For the 13.1 ft. (4 m) soil thickness, TCP soil concentrations are about 6 mg/kg at 3 ft. (0.91 m) and about 1 mg/kg at 1 ft. (0.3 m) after 5 years. After 10 years, TCP soil concentrations are about 30 mg/kg at 3 ft. (0.9 m) and about 8 mg/kg at 1 ft. (0.3 m). Similar profiles are found for xylenes. At steady-state, there is a linear decrease in soil concentrations from the base of the excavation to the ground surface. The steady-state soil concentrations for the principal VOCs are summarized in Table 6 for a mid-depth position in the soil profile and at a depth of 1 ft. for both the 6.5 ft. and 13.1 ft. soil thicknesses.

Table 4. Estimated soil-air concentrations in areas containing DNAPL.

Compound	Soil-Air Conc. (mg/L)
1,2,3-TCP	5.5
Xylenes	20
Ethylbenzene	8.5
Toluene	24
PCE	3.7
TCE	1.8
Benzene	1.8
Total VOCs	65

Table 5. Estimated soil concentrations at the base of the excavation in areas containing DNAPL.

Compound	Soil Conc. (mg/kg)
1,2,3-TCP	300
Xylenes	200
Ethylbenzene	350
Toluene	290
PCE	20
TCE	5.5
Benzene	5.3
Total VOCs	1,170

Table 6. Summary of steady-state soil concentrations in areas containing DNAPL.

Compound	Conc. at Mid-Depth of Soil Profile (mg/kg)	Conc. at 1 ft. Depth for 6.5 ft. Soil Thickness (mg/kg)	Conc. at 1 ft. Depth for 13.1 ft. Soil Thickness (mg/kg)
1,2,3-TCP	150	46	23
Xylenes	100	31	15
Ethylbenzene	175	54	27
Toluene	145	45	22
PCE	10	3.1	1.5
TCE	2.8	0.85	0.42
Benzene	2.7	0.85	0.40
Total VOCs	585	180	89

4.3 Non-DNAPL-Containing Areas

In areas within the former lagoons where no DNAPL is present in the soils or bedrock below the water table, the VOC concentrations in the soil air in the unsaturated zone will be considerably lower than those areas that contain DNAPL. The average soil concentrations found in the non-DNAPL containing areas, are found in Table 8 of the Exposure Assessment Memorandum prepared by ENVIRON, and are summarized here in Table 7.

The soil air concentrations that would be caused by the lower level soil contamination were estimated by:

$$C_a = \frac{C_t \, \rho_b \, H}{K_d \, \rho_b + \theta_w + H \, \theta_a}$$

where:

C_t	is the total soil concentration
C_a	is the concentration in the soil air
H	is the dimensionless Henry's Law Constant
θ_a	is the air-filled porosity.
θ_w	is the water-filled porosity.
ρ_b	is the dry bulk density of the soil
K_d	is the partition coefficient for the lagoon-area soil

The in situ lagoon area soils differ in properties from the backfilled soils. It is assumed that the in situ lagoon-area soils have a porosity of 0.45, a water content of 0.20, and an organic carbon content of 1.0 %. The calculated vapor concentration in soil air in the non-DNAPL containing areas are shown in Table 7.

Table 7. Average soil concentrations in non-DNAPL containing areas in lagoon-area soils.

Compound	Average Soil Concentration (mg/kg)	Soil Air Concentration (mg/L)
1,2,3-TCP	2.7	0.053
Xylenes	13	1.5
Ethylbenzene	3.1	0.073
Toluene	78	6.4
PCE	1.4	0.27
TCE	1.3	0.44
Benzene	1.3	0.45
Total VOCs	100	9.2

Based on the vapor transport simulations and the vapor concentrations noted above, soil concentration profiles above non-DNAPL containing areas were calculated. These profiles are shown for TCP in Figures 11 and 12, and for xylene in Figures 13 and 14. TCP and xylene concentrations in soil close to the water table are about 3 mg/kg and 13 mg/kg respectively.

For the 6.5 ft. (2 m) soil thickness, TCP soil concentrations are about 0.2 mg/kg at 3 ft. (0.9 m) and about 0.015 mg/kg at 1 ft. (0.3 m) after 1 year. After 4 years, TCP soil concentrations are about 1 mg/kg at 3 ft. (0.9 m) and about 0.3 mg/kg at 1 ft. (0.3 m). For the greater soil thickness, longer time periods are required to achieve comparable soil concentrations in the upper portions of the replaced soil. For the 13.1 ft. (4 m) soil thickness, TCP soil concentrations are about 0.06 mg/kg at 3 ft. (0.91 m) and about 0.01 mg/kg at 1 ft. (0.3 m) after 5 years. After 10 years, TCP soil concentrations are about 0.3 mg/kg at 3 ft. (0.9 m) and about 0.08 mg/kg at 1 ft. (0.3 m). Similar profiles are found for xylenes. The steady-state soil concentrations for the principal VOCs are summarized in Table 8 for a mid-depth position in the soil profile and at a depth of 1 ft. for both the 6.5 ft. and 13.1 ft. soil thicknesses.

Table 8. Summary of steady-state soil concentrations non-DNAPL areas.

Compound	Conc. at Mid-Depth of Soil Profile (mg/kg)	Conc. at 1 ft. Depth for 6.5 ft. Soil Thickness (mg/kg)	Conc. at 1 ft. Depth for 13.1 ft. Soil Thickness (mg/kg)
1,2,3-TCP	1.4	0.42	0.21
Xylenes	6.5	2.0	1.0
Ethylbenzene	1.6	0.48	0.23
Toluene	39	12	6.0
PCE	0.7	0.21	0.11
TCE	0.65	0.20	0.10
Benzene	0.65	0.20	0.10
Total VOCs	50	15	7.8

5. Conclusions

Following excavation of contaminated lagoon area soils above the top of the saturated zone and placement of the clean fill, voc vapors from contaminated soil and bedrock beneath the former lagoons will diffuse upward into the backfilled soil. These vapors will migrate upward through the backfilled soil toward the ground surface and will result in contamination of the formerly clean fill material. The vapor transport model simulations and calculations described in this report illustrate that vapor migration and contamination of the clean fill may occur to a significant degree over a period of several years. Steady-state concentration profiles develop in 4 years to 10 years for TCP, and 1 year to 3 years for xylenes. The levels of soil contamination at a depth of 1 ft. in the backfill which can result from the upward migration of vapors are as high as 10 to 30 mg/kg for both TCP and xylenes.

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Figure 1. TCE concentrations in soil gas and calculated soil concentrations above a shallow groundwater plume. Data from Rivett (1993).

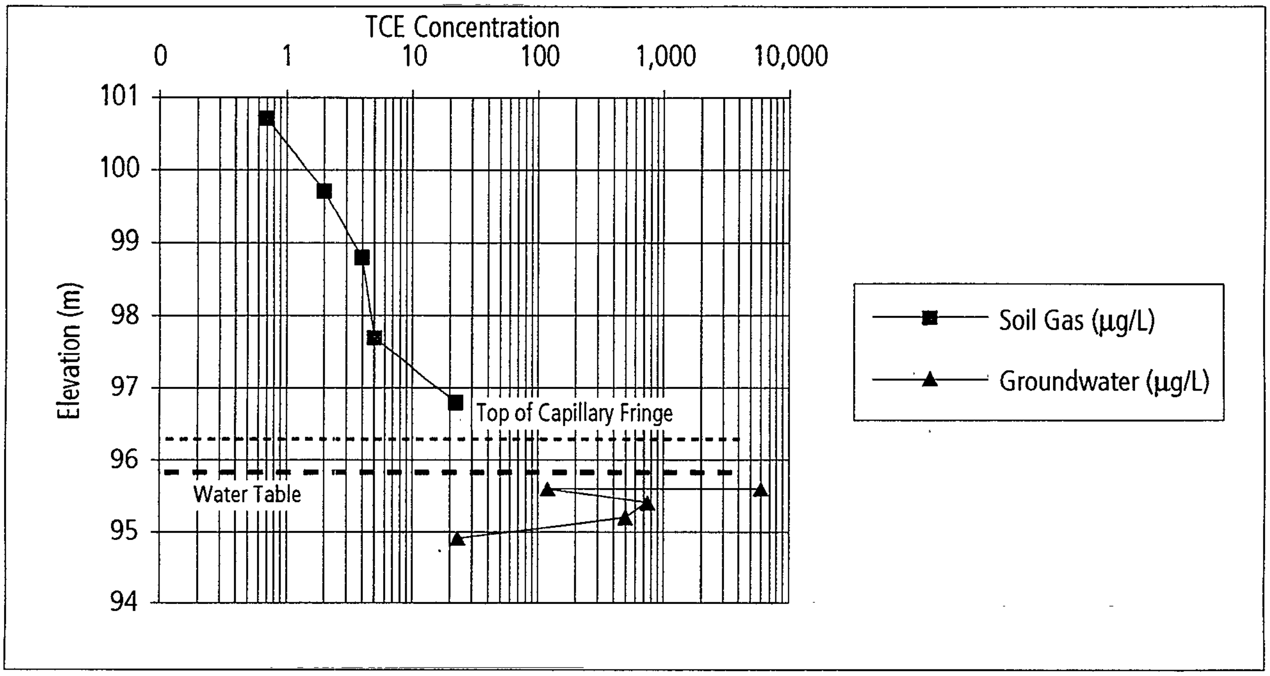

Figure 2. TCE concentrations in soil gas and calculated soil concentrations above a shallow groundwater plume. Data from Smith et al. (1990).

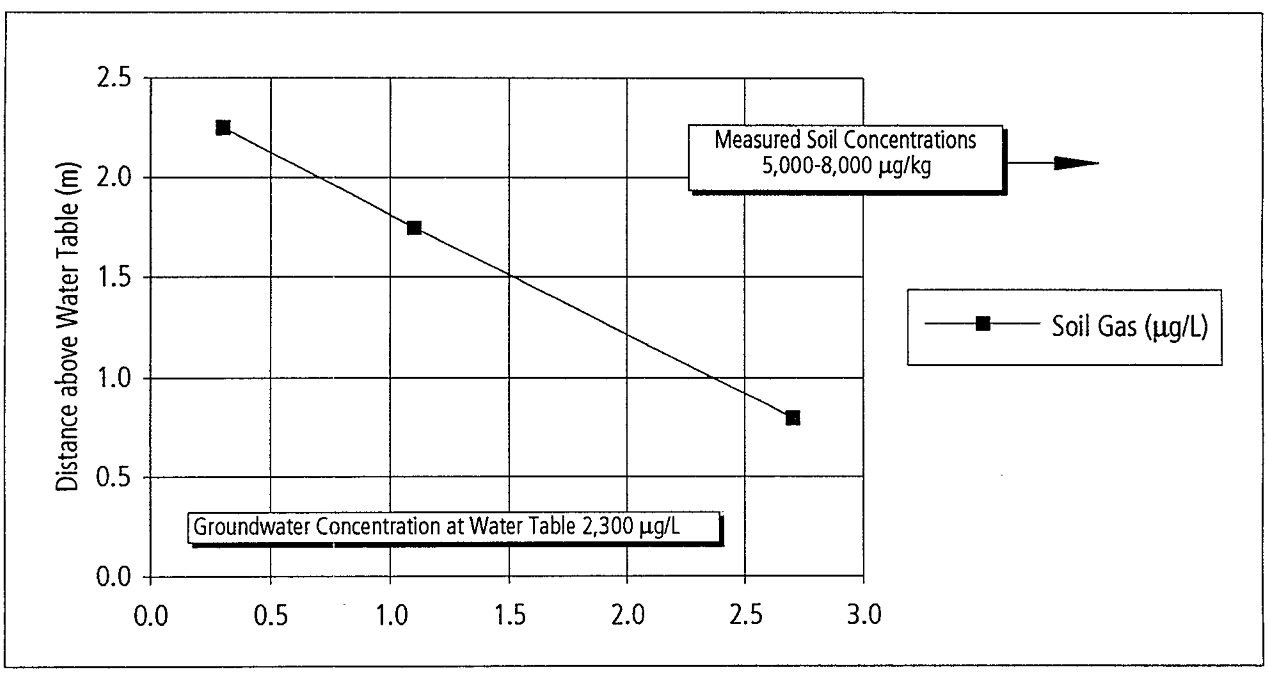

Figure 3. Vapor concentration profile for TCP for 6.5 ft. soil thickness.

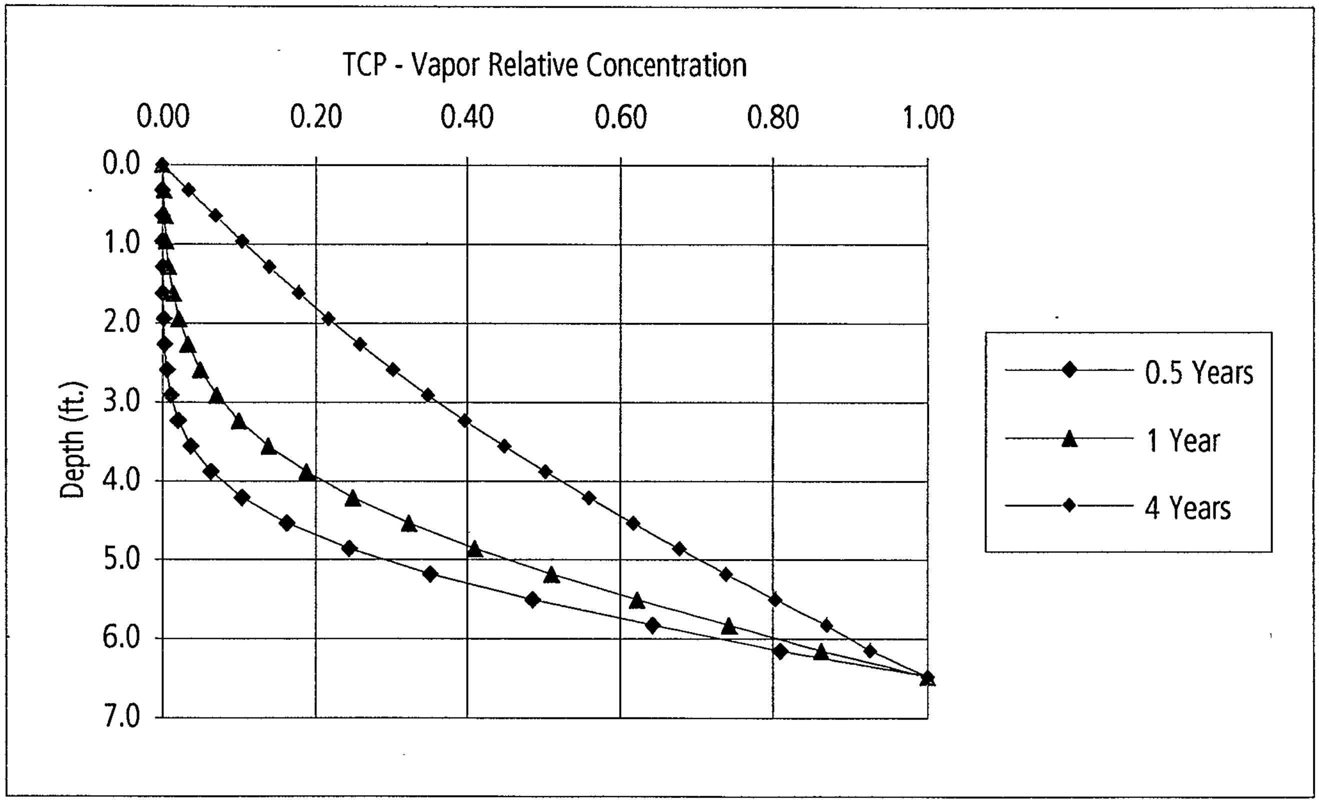

Figure 4. Vapor concentration profile for TCP for 13.1 ft. soil thickness.

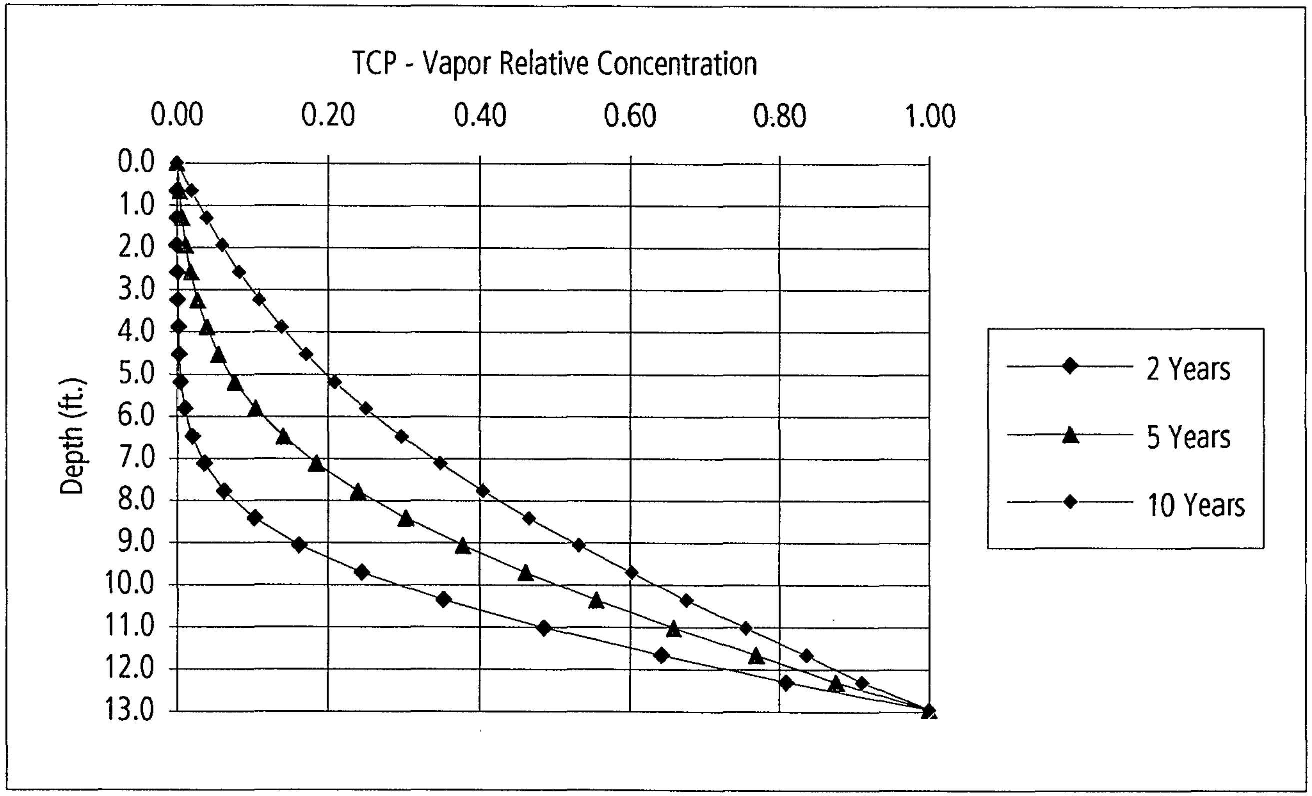

Figure 5. Vapor concentration profile for xylene for 6.5 ft. soil thickness.

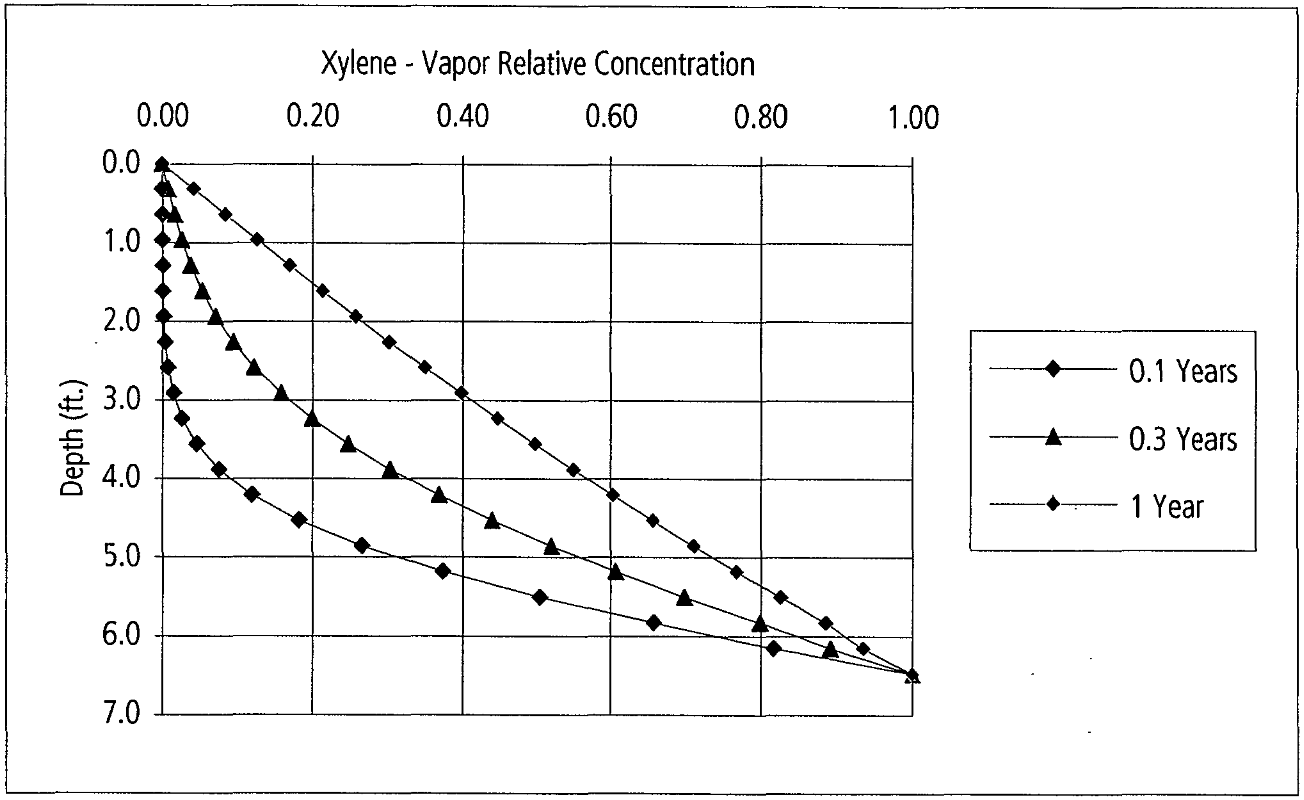

Figure 6. Vapor concentration profile for xylene for 13.1 ft. soil thickness.

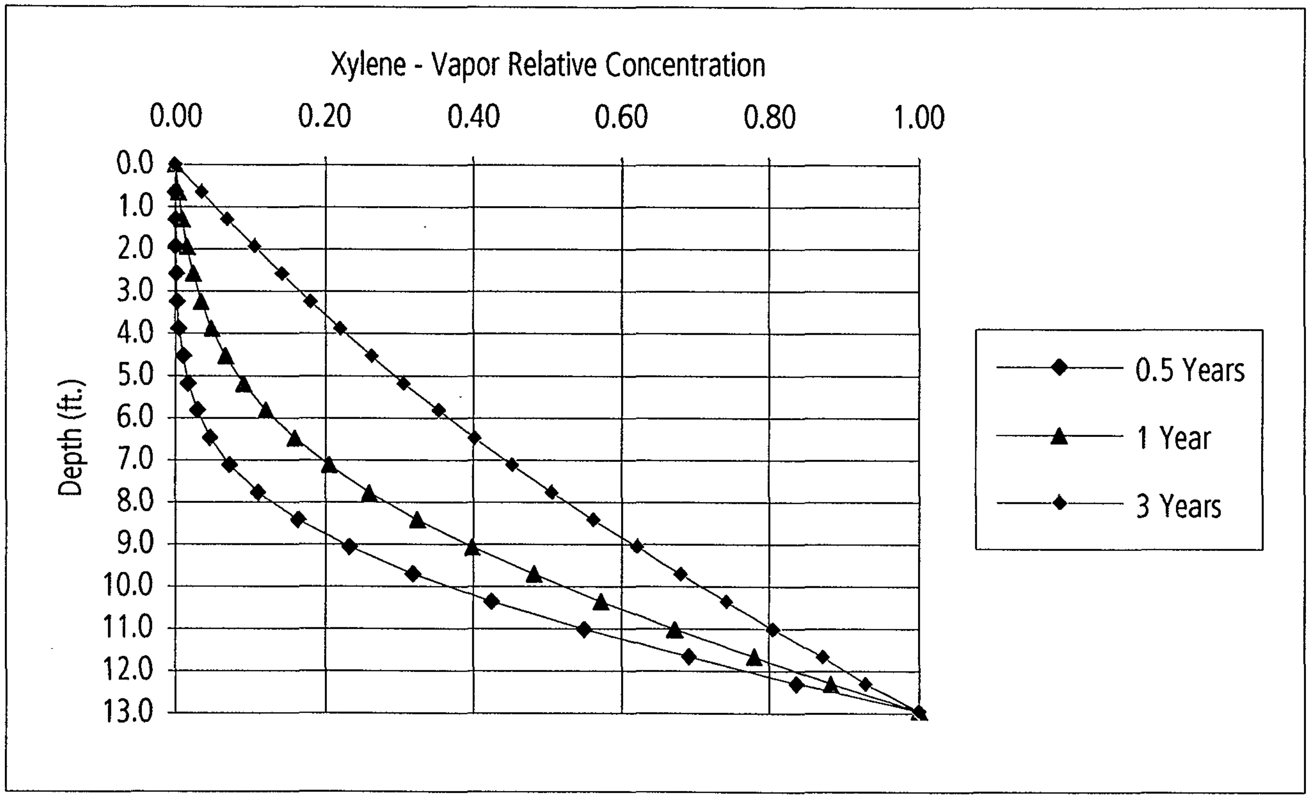

Figure 7. DNAPL-containing area -
Soil concentration profile for TCP for 6.5 ft. soil thickness.

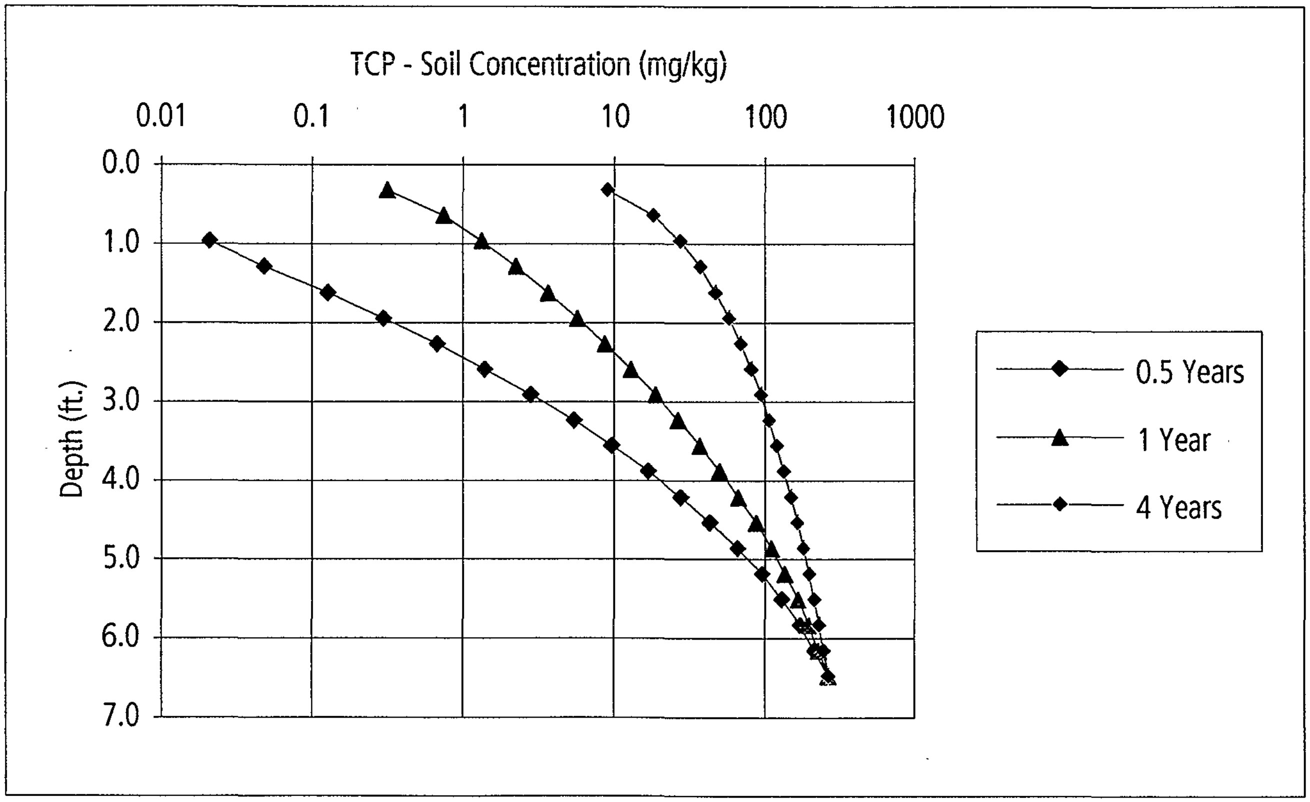

Figure 8. DNAPL-containing area -
Soil concentration profile for TCP for 13.1 ft. soil thickness.

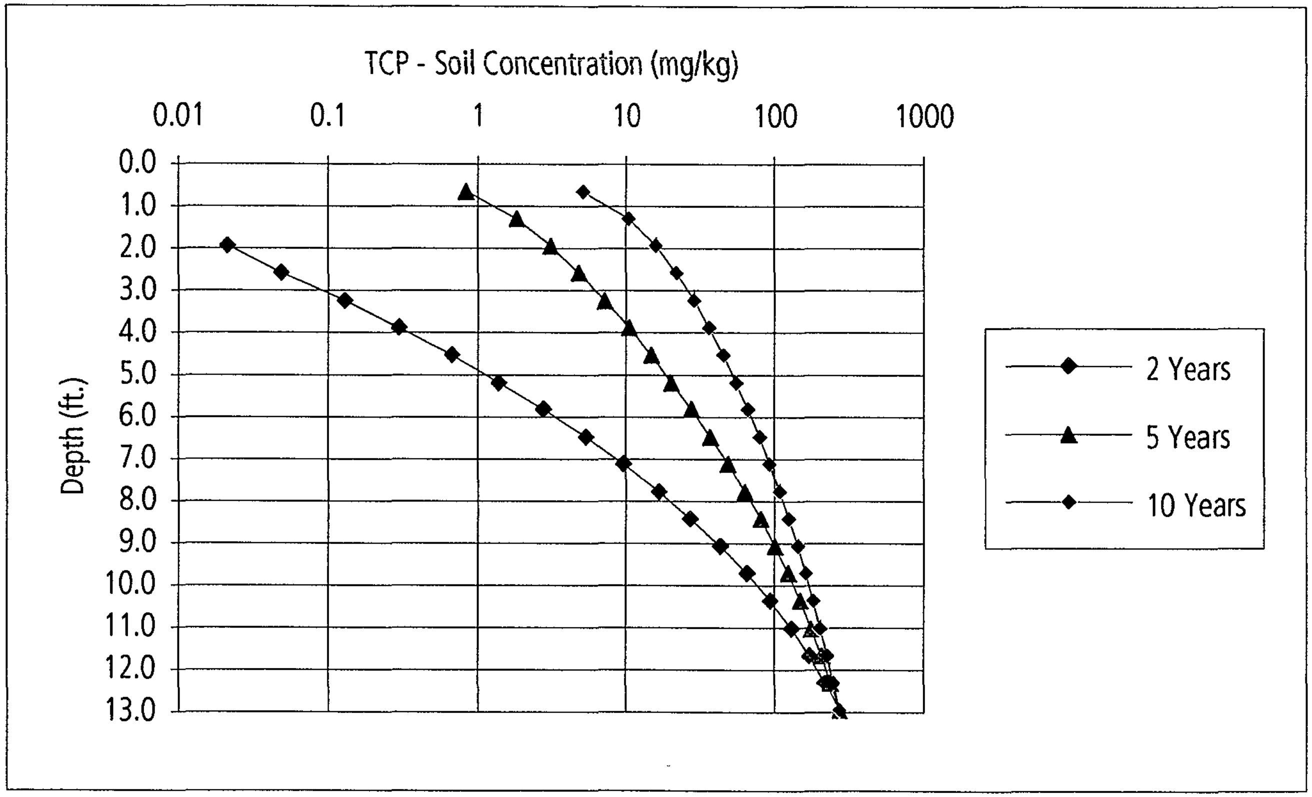

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Figure 9. DNAPL-containing area -
Soil concentration profile for xylene for 6.5 ft. soil thickness.

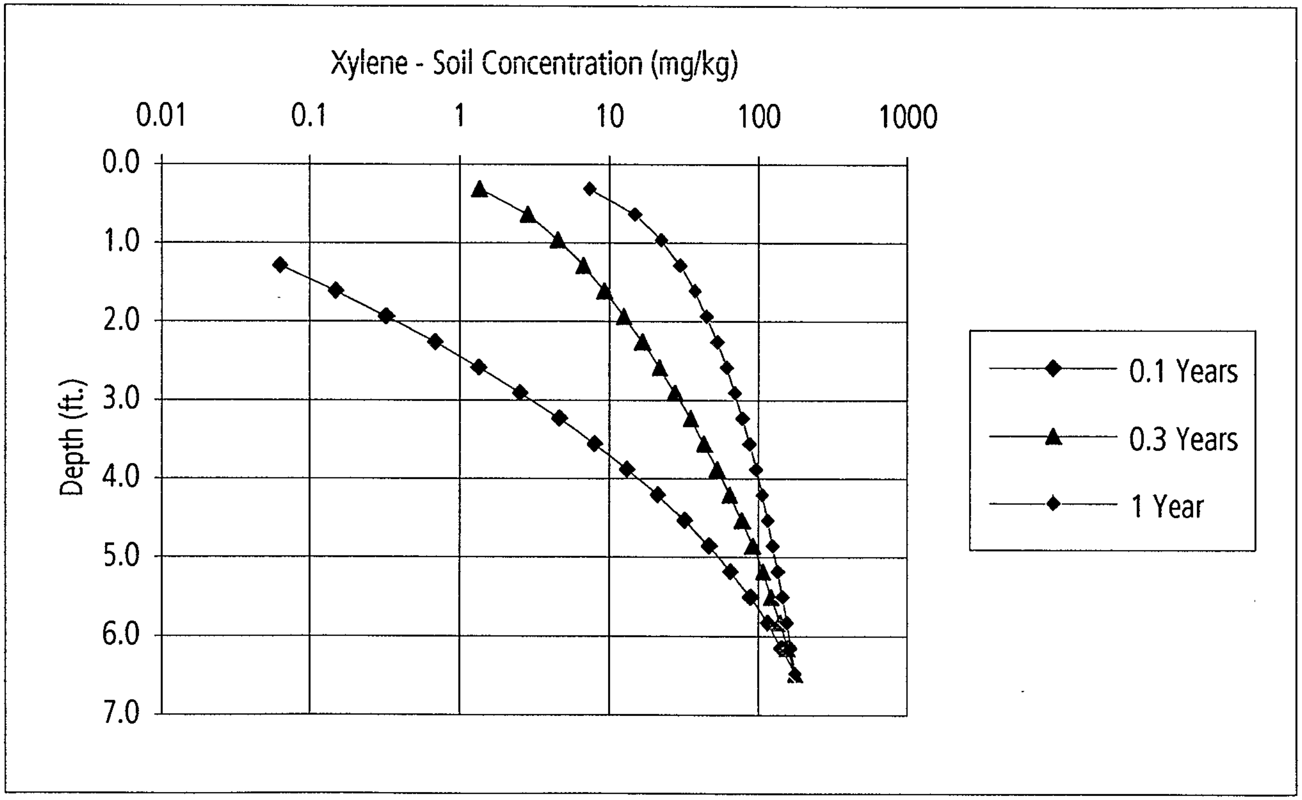

Figure 10. DNAPL-containing area -
Soil concentration profile for xylene for 13.1 ft. soil thickness.

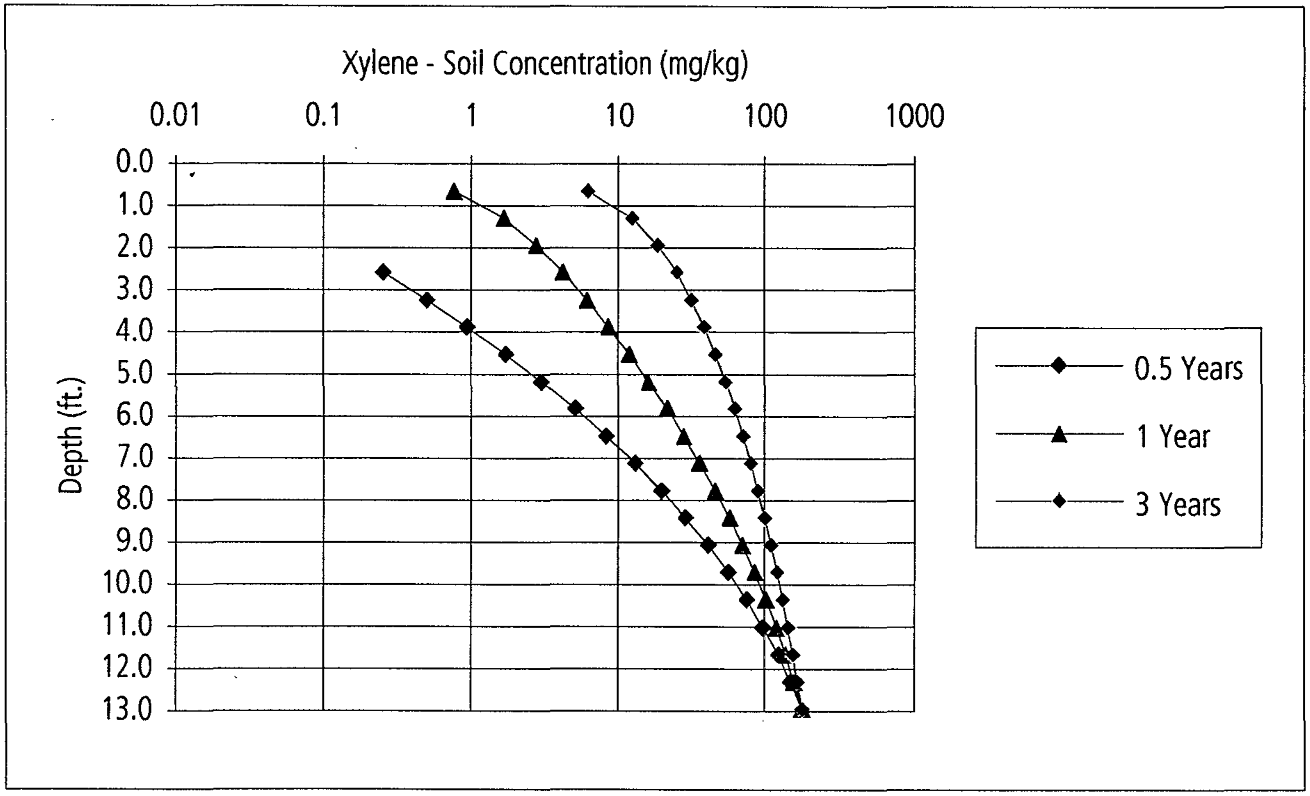

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Figure 11. Non-DNAPL containing area -
Soil concentration profile for TCP for 6.5 ft. soil thickness.

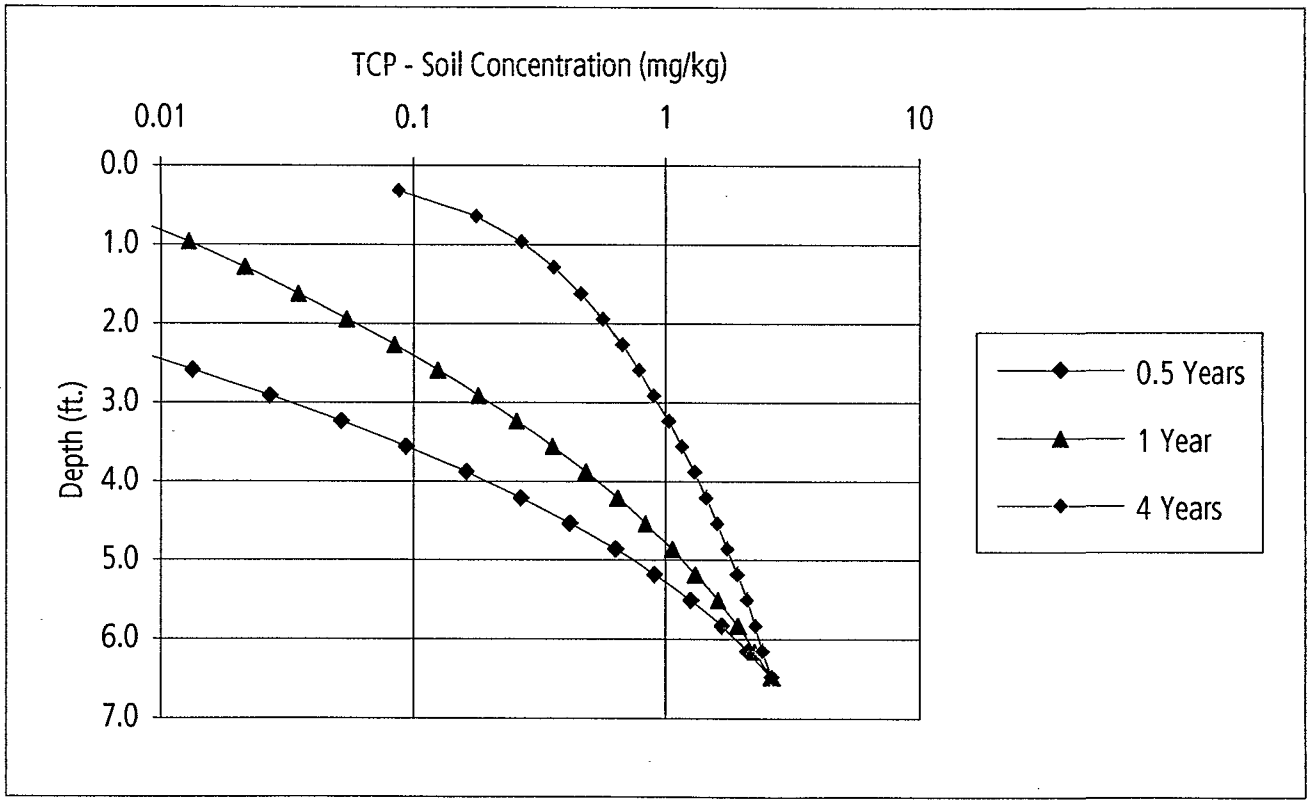


Figure 12. Non-DNAPL containing area -
Soil concentration profile for TCP for 13.1 ft. soil thickness.

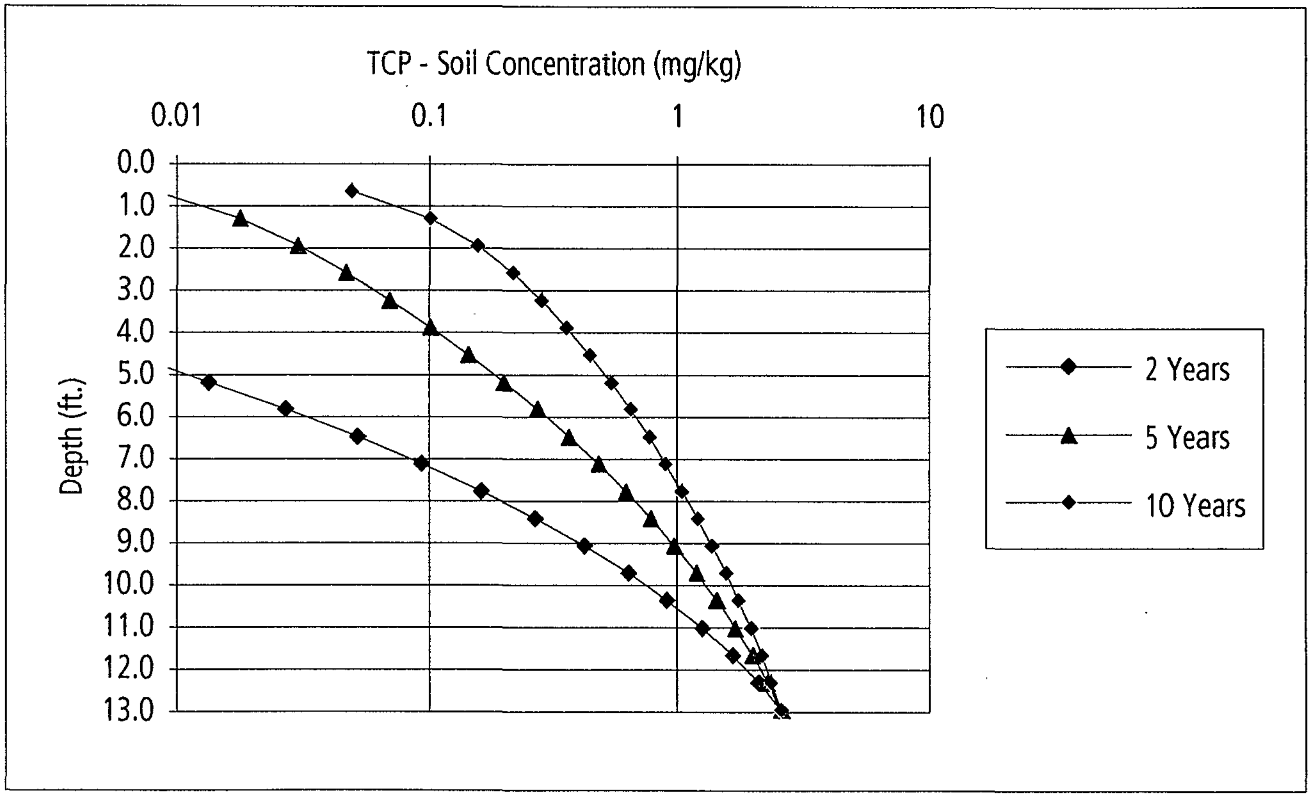


Figure 13. Non-DNAPL containing area -
Soil concentration profile for xylene for 6.5 ft. soil thickness.

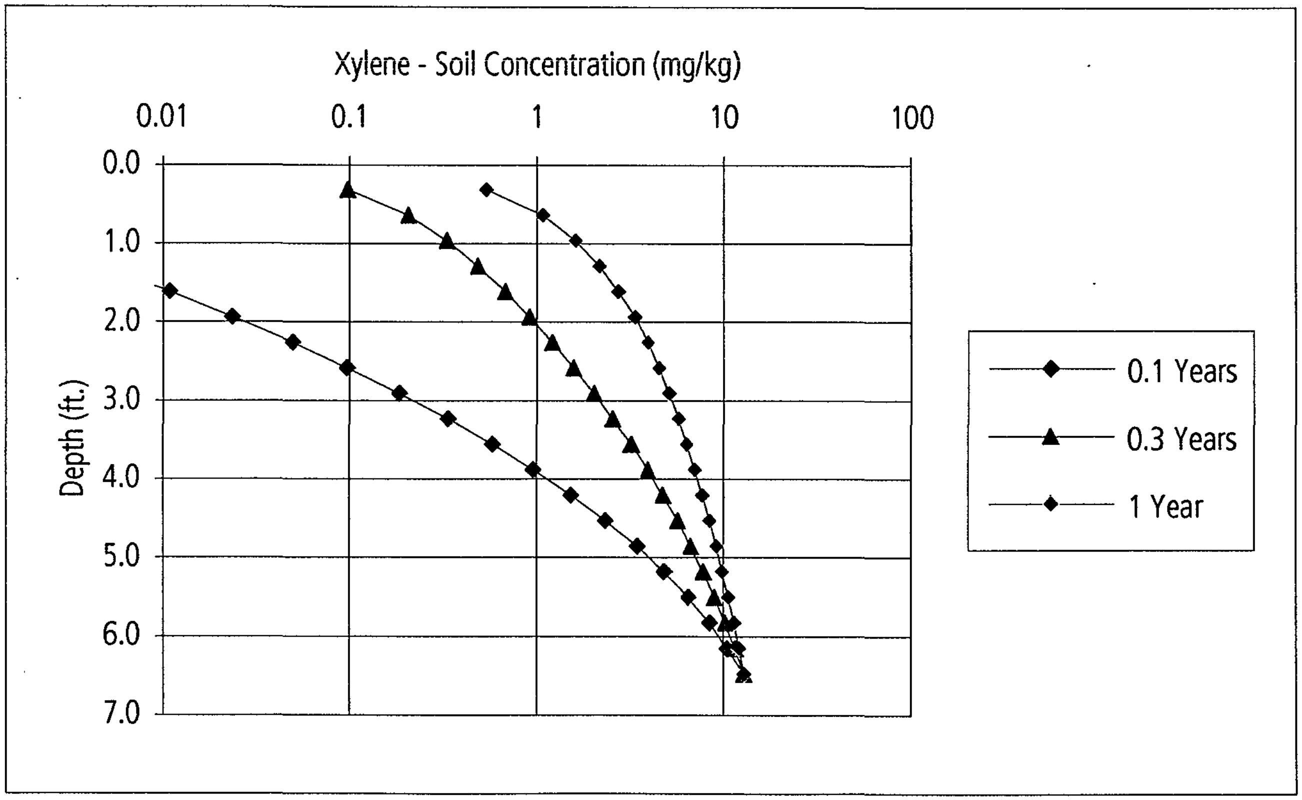
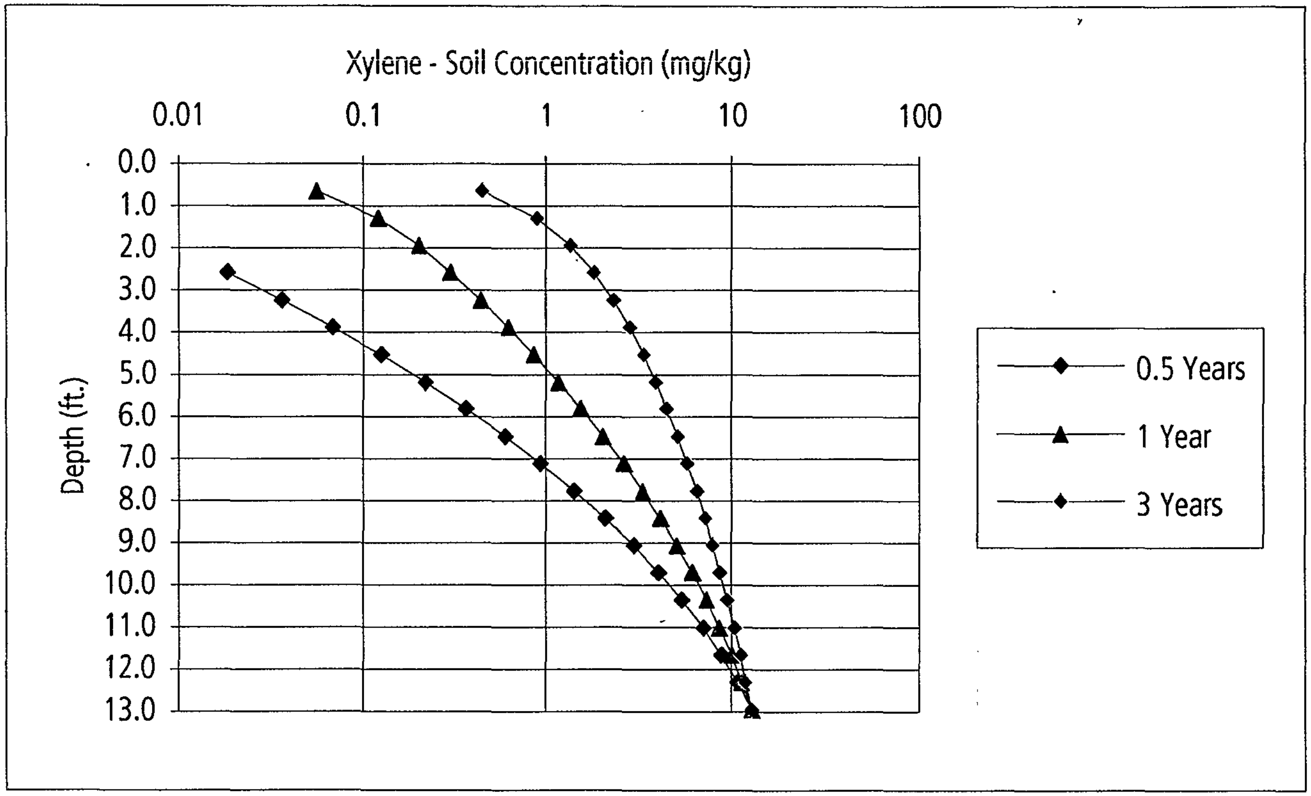


Figure 14. Non-DNAPL containing area -
Soil concentration profile for xylene for 13.1 ft. soil thickness.



Appendix E
Bedrock and Soil Sealing for the Tyson's Lagoon Area Soils

BEDROCK AND SOIL SEALING FOR THE TYSON'S LAGOON AREA SOILS
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1.0 INTRODUCTION

1.1 OBJECTIVE

The potential remedies for the lagoon area soil at the Tyson's Site include various treatment methods involving excavation of the contaminated soil. Two broad options were identified for evaluation in this appendix. The first option is full excavation of the lagoon soils to the top of bedrock. This will require excavating a substantial volume of soil below the ground water table. The second option limits excavation only to unsaturated soils, leaving the saturated zone soils as part of the site-wide ground water remediation.

After excavation and treatment, the excavation area will be backfilled with treated or imported clean soil. Unless engineering control measures are implemented, backfilled soil will be under the contaminated ground water or in direct contact with the contaminated soil and bedrock. This will lead to recontamination of backfilled soil by VOC migration and direct contact. If prevention of recontamination is a goal, clean backfilled soil must be protected from the contaminated media with a physical barrier. This report evaluates the applicability of potential barrier options to prevent recontamination for remedial actions involving excavation of the lagoon area soil.

1.2 SOIL RECONTAMINATION MECHANISM

Recontamination of the clean soil may occur by two mechanisms. The first mechanism is direct contact with contaminated ground water and subsequent adsorption of contaminants to soil particles. This mode of recontamination (aqueous migration) will occur in soils backfilled in the saturated zone below the high water level and capillary zone. Since ground water contaminant concentrations may vary from a few parts per million to greater than 1,000 ppm (concentrations associated with DNAPL), saturated backfilled soil may have corresponding equilibrium concentrations as a result of aqueous migration.

The second mechanism is molecular diffusion driven by the difference in chemical concentration between two points. Diffusion may occur through two different media: air and water. Diffusion through air occurs very quickly and is referred to as gaseous diffusion. Diffusion through water occurs slowly and is referred to as aqueous diffusion. For organic chemicals of concern found at the Tyson's Site, gaseous diffusion is about four orders of magnitude faster than aqueous diffusion.

Gaseous diffusion occurs by diffusion of VOC vapors through air in the soil pore spaces. In this process, VOC vapors will dissolve into soil water and then be adsorbed onto the organic fraction of soil solids, causing recontamination of the soil medium in the unsaturated zone. Aqueous diffusion occurs through water-filled voids of the saturated zone soils. For typical unsaturated soils with mixed air and water voids, gaseous diffusion is predominant and aqueous diffusion may be ignored. Further details of the recontamination mechanisms are presented in FFS Appendix D.

According to FFS Appendix D, vapor diffusion may recontaminate backfilled soils with TCP to a nearly steady state within 4 years for shallow backfill (6.5 ft) and within 10 years for deeper backfill (13 ft). Backfilled soil immediately above areas containing DNAPL may have TCP concentrations of 300 mg/kg after recontamination, and total VOC concentrations above 1,000 mg/kg.

2.0 BARRIER FUNCTIONS AND OPTIONS

2.1 BARRIER FUNCTIONS AND PERFORMANCE REQUIREMENTS

2.1.1 *General Barrier Applications*

Barriers generally provide containment by enclosing the contaminated media or waste to minimize the release of the waste constituents by a carrier medium, usually water. Barriers achieve containment by one or more of the following functions:

- Minimize the inflow of water into the containment zone using covers, vertical wall barriers and bottom barriers to prevent leachate generation;
- Allow recovery of any leachate formed in the source area using leachate removal systems;
- Minimize the release of leachate to the extent practicable using bottom and sidewall barriers; and
- Attenuate the impact of release to an acceptable risk level aided by various natural processes such as sorption, degradation and dilution.

Barriers, are evaluated and selected based on their ability to minimize and attenuate releases. The performance of barriers may be satisfactory even if they leak. A barrier system fails when the consequences of such releases lead to an unacceptable risk.

2.1.2 *Barrier Application to Tyson's Site*

The functions and the performance requirements of barriers for the Tyson's Site are quite different from those of barriers used for typical environmental applications. The differences are as follows:

- Typical barrier applications are intended to minimize leakage from a contained zone of contamination. Barriers for the Tyson's Site are intended to eliminate leakage into a contained zone of clean backfill.
- In typical applications, minor leakage of contaminants is expected and acceptable. At the Tyson's Site, the goal of the barrier is to protect the

clean backfilled soil. Even at a low leakage rate, contaminants will pass through the barrier and recontaminate the clean backfilled soil.

2.2 *BARRIER OPTIONS*

Diverse material types and installation methods are available for barrier options (EPA, 1985). The following are examples of barrier options that may be applicable for sealing the bedrock or soil:

- Soil-based liners using natural clay or bentonite-modified soils;
- Grouting of bedrock fractures or porous soil matrix based on cement or various chemicals to reduce the permeability of the geologic medium; and
- Surface sealing using manufactured barrier products such as polymer coating, bentonite mats or flexible membrane liners (FMLs).

More specifics of each barrier category are discussed below.

2.2.1 *Clay and Soil-Bentonite*

Clay and bentonite modified soil barriers are one of the most common methods of isolating wastes and contaminated media in environmental applications. Typically, clays or bentonite-modified soils are compacted over the sealing area to form about 2-ft thick barrier layer. The soil-bentonite slurry wall is a special application of the soil-bentonite barrier in which a vertical barrier is constructed using a thick bentonite slurry.

Clay and bentonite provide a low-permeability barrier to reduce water flow. Since these barriers are almost always saturated with water, they can reduce diffusive migration to a minimum by forcing chemical diffusion to occur through water rather than through air. In general, clay liners and slurry walls are required to achieve a hydraulic conductivity of $1x10^{-7}$ cm/sec or less (EPA, 1985). This requirement also signifies that these barriers are intended to "minimize" the leakage rate to an acceptable level rather than to "completely eliminate" it.

2.2.2 *Grouting*

Grouting is a process of injecting a preformulated fluid medium, designed to set in the subsurface, into rock or soil to reduce water flow (EPA, 1985). Cement grouting is most common. Chemical grouting, based on various silicates or organic polymers, is gaining acceptance for smaller and specialty projects. Chemical grouting is more effective than cement grouting in penetrating fine rock fissures and soil (Karol, 1990). Therefore, chemical grouting is the basis for discussions of grouting in this appendix.

2.2.3 *Flexible Membrane Liners*

Currently FMLs are most widely used as barrier materials for environmental uses. Although FMLs possess excellent barrier properties, they are not an absolutely impermeable material. Leakage occurs in two different modes: transmission directly through the intact membrane at a very low rate (i.e., diffusion of vapor molecules) and leakage through liner defects (EPA, 1991). Diffusive transmission of water is negligible as compared to leakage through the defects. VOC vapors, depending on the molecule size and polarity of the chemical and the type of FML, may migrate by diffusion through FMLs at much higher rates than water.

Liner defects include holes, tears, slits and defective seams that may develop during manufacture, transportation, storage, handling, and installation. FML defects may be minimized by quality control programs during manufacture, handling and installation. However, no method can completely eliminate potential defects. This is particularly true for the possible defects that may develop during and after soil backfilling in which virtually no quality control measures are available.

To consider inevitable defects, the current practice of FML design, evaluation and analysis assumes a certain level of defects and subsequent leakage of water through the defects. Examples include leachate detection and recovery systems and ground water monitoring required for bottom liners. Another example is the leakage fraction concept used in the liner performance evaluation process (Schroeder, et al., 1984).

2.2.4 *Other Barrier Options*

Other possible barrier options include gunite, sprayed polymeric liner and bituminous coating. Performance and limitations of these materials are similar to those of the above materials as summarized below:

- Gunite tends to develop hairline cracks due to shrinkage and uneven stress developed after backfilling. Gunite also allows water transmission at a low rate through the intact material.
- Bituminous materials are commonly used for basement water-proofing and may be used as a subsurface barrier wall. In basement

applications with adequate drain systems (e.g., outside french drains or inside floor drains), the bituminous seal provides reasonable waterproofing. However, leakage is very common without adequate drainage. Bituminous mixes used as liners or subsurface barriers achieve a permeability of 1×10^{-7} cm/sec (EPA, 1983). A mixture of asphalt emulsion, cement and sand marketed as "Aspemix" for vibrated-beam slurry walls can achieve a permeability of as low as 4×10^{-9} cm/sec (Anderson, undated). Considering the typical application thickness of 2 inches, the overall performance of Aspemix barrier is equivalent to that of a 24-in clay liner with a permeability of 1×10^{-7} cm/sec.

- Sprayed polymer liners, while better in fitting irregular surfaces, do not perform as well as FMLs due to field application conditions and limited quality control. Therefore, the leakage rate through a sprayed polymer liner may be higher than the leakage rate expected through an FML in a similar application.

3.0 *EVALUATION OF BEDROCK SEALING*

This section evaluates the applicability of various barrier options to sealing the bedrock surface below the water table. Bedrock sealing would be required if all lagoon soils, including the saturated zone, are excavated to top of the bedrock. The barrier used for bedrock sealing should prevent leakage of contaminated ground water into the backfilled soil zone and aqueous diffusion.

3.1 *CLAY AND SOIL-BENTONITE LINER*

Clay or soil-bentonite barriers will allow a low rate of seepage into the clean backfill. The barrier walls will be placed below the water table (most of the lagoon bottom is below the natural ground water table), the seepage rate per acre through a 2-foot thick clay liner may be estimated as follows:

Clay permeability = 1×10^{-7} cm/sec = 2.8×10^{-4} ft/day

Static head above the bottom of clay, typical = 5 ft

Thickness of clay liner = 2.5 feet

Hydraulic gradient = 5 ft/2 ft = 2.5

Q = kiA = 2.8×10^{-4} ft/day x 2.5 x 43,560 ft^2 = 30.5 cf/day/acre
= 11,000 cf/year (or 83,000 gal/year/acre)

Once passing through the barrier, the water will rise further and remain in the soil by capillary action. This will allow continued flow of water through the barrier layer without a significant decrease in the hydraulic gradient until the saturation level reaches the level of the surrounding water table. This resaturation will occur in a relatively short time as illustrated below:

Air porosity of the backfilled soil = 0.2

Annual volume of soil resaturation 11,000 cf/0.2 = 55,000 cf

Resaturated soil volume, including 4-ft capillary fringe, can be estimated from the typical resaturation zone thickness of 6 feet, based on the bedrock level and the static water level.

43,560 ft^2 x 6 ft = 261,360 cf

Resaturation time 261,360/55,000 = 5 years

The above analysis shows that clay or soil-bentonite barriers cannot prevent recontamination of the backfilled soil but only postpone it. Therefore, clay and bentonite barriers are not a practical means of providing ultimate protection against aqueous recontamination.

3.2 *GROUTING*

Bedrock grouting at the Tyson's Site would be applied in both saturated lagoon bottom and unsaturated sidewalls. In saturated bedrock, grouting can reduce seepage of ground water into the backfilled clean soil. In unsaturated bedrock, grouting can reduce vapor diffusion by decreasing the air porosity in the unsaturated sidewall of the former lagoons.

At the Tyson's Site, grout would be injected into the lagoon bottom and sidewall after excavation of the lagoon soil. Holes approximately two inches in diameter would be drilled into the bedrock about 10 feet deep at a spacing of about 10 feet. Grout would be pumped into the holes at a relatively low pressure (high pressure injection is not appropriate for shallow depth injection) to form a grout blanket about 10 feet thick over the lagoon area bottom and sidewalls. This grout blanket, because of its low permeability, would reduce seepage of ground water into the backfilled soil zone.

Documented effectiveness of chemical grouting in reducing seepage includes the following (Karol, 1990):

- In 1982, chemical grouting was used to control seepage through the embankment from an ash basin in Pennsylvania. After the grouting program, the seepage rate of 35 gpm was reduced by 94% to 2 gpm.
- In 1983, chemical grouting was used to control seepage from the tunnel wall of the brewery museum owned by Miller Brewing Company. Chemical grouting achieved a 95% seepage cutoff.
- In the late 1950s, chemical grouting in combination with cement-clay and cement-bentonite grouting was used to control seepage through the old riverbed at the dam site for the Rocky Reach Hydroelectric Project. The cutoff effectiveness measured in this grouting program was about 89%.

Based on the nature of grouting and the above case histories, grouting can reduce seepage but cannot completely eliminate it. For most intended applications, grouting achieves sufficient reduction of seepage. If grouting is used at the Tyson's Site the ground water will flow through the grouted zone at a low rate. Although the grouted zone is five times thicker than the clay barrier, the hydraulic conductivity of the grouted bedrock is typically an order of the magnitude higher (references). Thus, grouting will not be as effective as clay liners in minimizing leakage.

3.3 *FMLS*

Although FMLs or geomembrane materials are relatively impermeable to water, leakage occurs through holes in liner materials and defective seams between liner sheets. Factors leading to such holes and defects include material imperfections, installation damage, sharp objects and rocks in the subgrade, construction traffic, long-term stress, seaming imperfections, and chemical degradation. Even with strict quality assurance/quality control (QA/QC) requirements, leaks in geomembrane liners are virtually unavoidable. Typical rates of leakage through liner materials have been estimated from 0.1 gallons per acres per day to over 200 gallons per acre per day (Giroud, 1990).

Because of the inevitable defects and resulting leakage through FML materials, the current practice for liner design is to assume a certain level of leakage of water through the defects. Like clay barriers any leakage is considered a failure.

3.4 *DEWATERING*

In other barrier options, the driving force for leakage of contaminated ground water is hydrostatic pressure below the barrier higher than that above the barrier. Lowering the ground water table below the barrier can relieve this hydrostatic pressure and leakage. However, if dewatering is employed, temporary interruptions are expected. As soon as pumping is interrupted, the ground water table will recover and start to seep into the backfilled soil. Additionally, dewatering does not prevent vapor phase migration of contaminants. Therefore, dewatering is not a permanent and reliable method to protect the clean soil from recontamination. Containment by dewatering is not consistent with current regulatory policy. Pennsylvania Hazardous Waste Regulations require separation of the bottom of landfills from the ground water table and do not permit artificial lowering of the ground water table.

4.0 *EVALUATION OF SOIL SEALING*

4.1 *BARRIER SELECTION*

The primary function of a barrier in the unsaturated zone is to control vapor diffusion of organic chemicals into the backfilled soil. As indicated in Sections 2 and 3, FMLs which are most commonly used to control water migration, are not effective at restricting vapor phase migration of VOCs. Consequently, vapor phase diffusion can only be accomplish by using a saturated barrier layer to force the migration of chemicals to be limited to the rate that will occur by aqueous diffusion. This is effective because the aqueous diffusion rate is about four orders of magnitude lower than the vapor diffusion rate.

Clay is the most obvious material to be applied as a VOC migration barrier because of its naturally high capacity for water absorption and retention. Grouts can also be used as a saturated barrier, but their permeability is much greater than clay. Therefore, the following discussion of VOC migration and resulting recontamination are based on a barrier constructed of low permeability clay.

4.2 *EVALUATION OF DIFFUSIVE MIGRATION*

4.2.1 *Aqueous Diffusion through Barrier Layer*

The aqueous diffusion process through a saturated layer may be estimated using the Fick's Law as follows:

$$J_1 = D^* (C_{wo} - C_{wi})/L_1$$

$$D^* = \omega D_w$$

Where

J_1 Flux rate through the barrier ($g/sec.cm^2$)

D^* Effective aqueous diffusion coefficient of the chemical through the barrier (cm^2/sec)

C_{wo} Chemical concentration in water at the bottom of the barrier (g/cm^3)

C_{wi} Chemical concentration in water at the interface of the barrier and the backfilled soil (g/cm^3)

L_1 Thickness of the barrier layer, use 30 cm

ω An empirical coefficient for effective diffusion

D_w Free water diffusion coefficient of the chemical

To simplify calculation and presentation of the key points, the following calculations will use TCP as the representative chemical at the site without considering equilibrium of various chemical mixtures. The values of w depend on the type of the barrier material. For geologic materials, the w values are between 0.01 and 0.5 (Freeze and Cherry, 1979), depending on the soil type. Clay soils have low end w values and sands/gravels have high end w values. For barrier materials considered for bottom sealing (e.g., clay, soil-bentonite, grouted soil, etc.), ω would be about 0.05 or lower. The resultant D* value and flux rate are as follows;

D_w for TCP 7.8E-6 cm^2/sec

D* for TCP 0.05 x 7.8E-6 = 0.39E-6 cm^2/sec

C_{wo} for TCP 42.5xE-6 g/cm^3 (from Terra Vac, 1993)

$$J_1 = 0.39E\text{-}6(42.5E\text{-}6 - C_{wi})/30 = 1.3E\text{-}8(42.5E\text{-}6 - C_{wi}) \quad (1)$$

To evaluate the flux rate J_1, the TCP concentration in water at the interface (C_{wi}) should be known. The C_{wi} may be evaluated using the TCP diffusion through the backfilled soil.

4.2.2 *Diffusion through Backfilled Soil*

The TCP breaking through the barrier layer will continue migrating to the ground surface by gaseous-phase diffusion through soil air in the unsaturated backfilled soil. This gaseous diffusion may be expressed as follows:

$$J_2 = D_e C_{ai}/L_2$$

$$D_e = [D_a (\theta_a)^{10/3}/(\theta_t)^2]$$

Where

J_2 TCP flux rate through the backfilled soil (g/sec.cm^2)

D_e Effective diffusion coefficient of TCP through soil air (cm^2/sec)

C_{ai} TCP concentration in air at the interface or at the bottom of the backfilled soil (g/cm^3)

L_2 Thickness of the backfilled soil layer, use 300 cm.

D_a Diffusion coefficient of TCP through free air (0.073 cm^2/sec)

θ_a Air-filled porosity of the backfilled soil, use 0.25

θ_t Total porosity of the backfilled soil, use 0.40

Using the values given above, the flux rate may be expressed as follows:

D_e for TCP $= 0.073 \times 0.25^{10/3}/0.4^2 = 0.0045\ cm^2/sec$

$J_2 = D_e C_{ai}/L_2$ $= 0.0045 \times C_{ai}/300 = 1.5E\text{-}5\ C_{ai}$ (2)

The unknowns in Equations (1) and (2) can be evaluated using the following relationship in the two layer diffusion process when a steady state is reached:

Flux through the barrier (J_1) = Flux through the backfilled soil (J_2)

$C_{ai} = H_c C_{wi}$

H_c = dimensionless Henry's Law constant, 0.0167 for TCP

$1.3E\text{-}8(42.5E\text{-}6 - C_{wi}) = 0.0167 \times 1.5E\text{-}5\ C_{wi} = 2.5E\text{-}7 C_{wi}$

$C_{wi} = 21E\text{-}7\ g/cm^3 = 2.1\ mg/l$

$C_{ai} = 0.0167\ C_{wi} = 0.035\ mg/l$

4.2.3 *Level of Recontamination*

From the equilibrium relationship between the soil water, soil air and soil solids, the total TCP concentration at the bottom of the backfilled soil would be:

$$C_t = (C_{ai}\theta_a + C_{wi}\theta_w + C_{si}\rho_b)/\rho_b$$

$$C_{si} = K_d C_{wi}$$

$$K_d = K_{oc}\, f_{oc}$$

Where,

θ_w	Volumetric water content of the backfilled soil, use 0.15
C_{si}	TCP concentration in soil solids at the interface
C_t	Total TCP concentration at the bottom of the backfilled soil
ρ_b	Dry Bulk density of the backfilled soil, use 1.6 g/cm^3
K_d	Partition coefficient between soil water and soil solids (mL/g)
K_{oc}	Organic carbon-water partition coefficient for TCP (= 72 mL/g)
f_{oc}	Fraction of organic carbon in soil, use 0.01

The resultant TCP concentration at the bottom of the backfilled soil is as follows:

$$C_{si} = 72 \times 0.01 \times 2.1 = 1.5 \text{ mg/kg}$$

$$C_t = (0.035\text{x}0.25 + 2.1\text{x}0.15 + 1.5\text{x}1.6)/1.6 = 1.7 \text{ mg/kg}$$

Where DNAPLs are present in the remaining soil, TCP concentration in the water under the barrier may approach the solubility limit of TCP (=1900 mg/L). In this case, the corresponding soil contamination at the bottom of the backfilled soil would be:

$$C_{t(max)} = 1.7 \times 1900/42.5 = 76 \text{ mg/kg}$$

As shown previously, the fraction adsorbed onto the soil solids accounts for the majority of the chemical mass in the soil. Other VOCs encountered at the Tyson's Site have K_{oc} values much higher than that of TCP. Higher K_{oc} values cause more mass adsorption onto the soil. Thus, the effect of the mixed chemicals in water will lead to higher VOC concentrations in the recontaminated soil than what was estimated above.

4.2.4 *Timeframe of Recontamination*

Backfilled soil recontamination would not be an issue if breakthrough does not occur for 100 years or more. If breakthrough occurs within a short timeframe such as 30 years or less, recontamination would be an issue and the barrier fails to serve its purposes. The following diffusion equation (Freeze and Cherry, 1979) may be used to evaluate breakthrough time:

$$C/C_o = \mathrm{erfc}\,[\,0.5X/(D_{er}\,t)^{0.5}] \qquad (3)$$

$$D_{er} = \omega D_w/R$$

Where:

C	TCP concentration at time t and at distance X from the source
C_o	TCP concentration at the source (X = 0)
erfc	Complementary error function
D_{er}	Effective diffusion coefficient of TCP with retardation
R	Retardation factor ($= 1 + \rho_b K_{oc} f_{oc}/\theta_t$)

The vapors dissolving into the soil water and adsorbing onto the soil solids tend to slow down or retard the progress of diffusive migration. The retardation factor and effective diffusion coefficient with retardation can be calculated as follows:

$$R = 1 + 72\text{x}0.01\text{x}1.6/0.4 = 3.88$$

$$D_{er} = 0.05 \times 7.8\text{E-}6/3.88 = 1\text{E-}7\ \text{cm}^2/\text{sec}$$

To calculate the breakthrough time using Equation (3), a concentration at the top of the barrier must be selected as indicating breakthrough. A convenient number for this breakthrough concentration is 0.01 which is small enough to represent the beginning of breakthrough, but large enough to give a meaningful value for erfc. Using this definition, the breakthrough time can be calculated as follows:

Distance to top of the barrier layer	X = 30 cm
Effective diffusion coefficient with retardation	1E-7 cm^2/sec

Breakthrough concentration at the top $C/C_o = 0.01$

From complementary error function table,

$$C/C_o = 0.01 = \text{erfc}\ (1.825)$$

From Equation (3),

$$0.5X/(D_{er}\ t)^{0.5} = 1.825$$

$$t = (X/3.65)^2/D_{er}$$

$$t = (30/3.65)^2/(1 \times 10^{-7}) = 6.8\text{x}10^8 \text{ sec} = 21.6 \text{ years}$$

Based on the above calculation and assumptions, breakthrough would occur in about 20 years.

5.0 *SUMMARY AND RECOMMENDATIONS*

Barrier technologies are frequently used to minimize the release of waste constituents from a containment zone to the surrounding environment. Releases at a low rate are acceptable for most environmental applications. However, to protect clean backfilled soil at the Tyson's Site, barriers should not allow any leakage of contaminants from the surrounding media into the backfilled soil. In addition, these barriers should protect the clean soil over a very long period of time until the aquifer remediation is completed. Currently, no barrier materials or methods can provide such protection. All barrier materials (clay, soil-bentonite, grouting, FMLs, etc.) allow some leakage of water and diffusion of organic chemicals, leading to inevitable recontamination of the backfilled soil.

The evaluation of soil sealing technologies concluded that soils placed above the saturated zone could be protected from vapor-phase recontamination in the short-term by a clay barrier constructed above the top of the saturated zone. However, long-term inspection and maintenance of the barrier would be difficult, and there would be additional short-term exposure risks during installation of a clay barrier in the subsurface (e.g., large working areas required). Weighing the benefits of protecting the relatively small volume of clean backfill soils that would be placed in the unsaturated zone against the implementation and maintenance concerns, the more appropriate solution is to locate the clay barrier at the surface to reduce VOC emissions to the atmosphere.

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